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EXPERIMENTAL EVALUATIONS OF SELECTED IMMERSION HYPOTHERMIA PROT--ETC(U)
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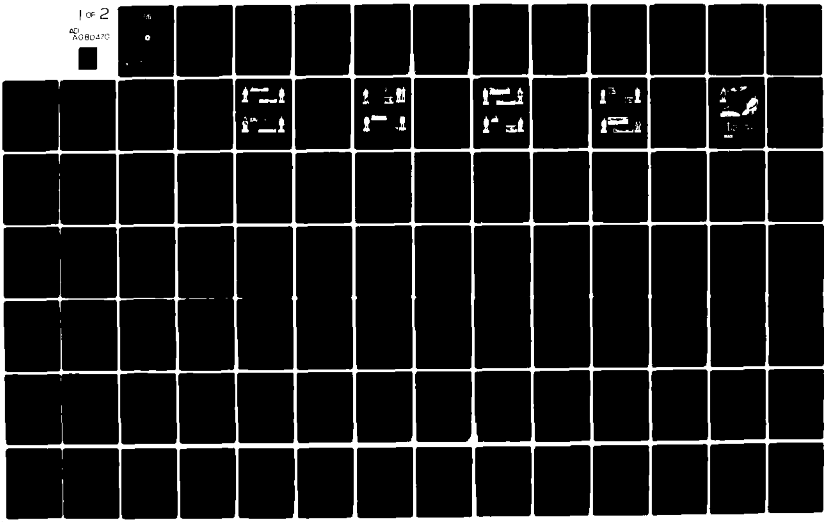

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16. Abstract

This report summarizes an experimental test program conducted with state-of-the-art hypothermia protection equipment. Tests included the following attributes: cold-protection effectiveness, mobility reduction, fatigue induction, ease of donning, buoyancy, aesthetic appeal/wearer confidence, flame resistance and reliability. Cold-protection effectiveness is expressed in terms of survival-time estimates for individuals, with selected body structures, wearing the test articles in 1.7°C (35°F) water. The data from these investigations is intended to collectively support the selection of equipment best suited for use by recreational boaters, Coast Guard crewmen and merchant mariners.

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PREFACE

This report documents work conducted under Task Number 3 of Contract Number DOT-CG-72074-A from June, 1978 to June 1979. The work was performed at Clemson University under the auspices of the U. S. Coast Guard with Lt.jg Steven F. Wiker and Ens. John A. Budde serving as program technical monitors. The principal investigator was Dr. R. Michael Harnett. Faculty associates participating in the research were Drs. Edward M. O'Brien, Fred R. Sias and James R. Pruitt. Graduate assistants participating in the research were Jim Strawhorn, Tom Horseman and Jay Smith.

TABLE OF CONTENTS

		Page
PART I	EXPERIMENTAL EVALUATIONS OF SELECTED IMMERSION HYPOTHERMIA PROTECTION EQUIPMENT	1
1.0	INTRODUCTION	1
	1.1 Background	1
	1.2 Objectives	2
	1.3 Scope	3
2.0	SELECTED TEST ARTICLES	4
	2.1 Selection Procedure	4
	2.2 Descriptions of Test Articles	6
	2.2.1 Wet Suits Covering Entire Body	8
	2.2.2 Wet Suits Covering Partial Body	10
	2.2.3 Dry Suits With Little Intrinsic Insulation	12
	2.2.4 Dry Suits With Foam Rubber Insulation	14
	2.2.5 Dry Suits With Air-Space Insulation	16
3.0	COLD-PROTECTION-EFFECTIVENESS INVESTIGATION	19
	3.1 Objectives	19
	3.2 Methodology	19
	3.3 Results	27
	3.4 Analysis and Discussion	32
	3.5 Special Observations	47
4.0	MOBILITY-REDUCTION INVESTIGATION	56
	4.1 Objectives	56
	4.2 Methodology	56
	4.3 Results	64
	4.4 Analysis and Discussion	66
5.0	FATIGUE-INDUCTION INVESTIGATION	69
	5.1 Objectives	69
	5.2 Methodology	69
	5.3 Results	75
	5.4 Analysis and Discussion	76

6.0 EASE-OF-DONNING INVESTIGATION.................................... 86
6.1 Objectives.. 86
6.2 Methodology... 86
6.3 Results... 92
6.4 Analysis and Discussion................................. 100
7.0 BUOYANCY INVESTIGATION.. 104
7.1 Objectives.. 104
7.2 Methodology... 104
7.3 Results... 105
7.4 Analysis and Discussion................................. 105
8.0 AESTHETIC-APPEAL/WEARER-CONFIDENCE INVESTIGATION.................. 108
8.1 Objectives.. 108
8.2 Methodology... 108
8.3 Results... 115
8.4 Analysis and Discussion................................. 115
9.0 FIRE-RESISTANCE INVESTIGATION..................................... 120
9.1 Objectives.. 120
9.2 Methodology... 120
9.3 Results... 122
10.0 RELIABILITY INVESTIGATION.. 126
10.1 Objectives and Methodology............................. 126
10.2 Results.. 126
11.0 SUMMARY.. 128
12.0 REFERENCES... 135

Appendix
A EQUIPMENT MANUFACTURERS/SUPPLIERS A-1
B COOLING TEMPERATURE PROFILES.. B-1
C STANDARD PROCEDURES FOR MEASURING ELEMENTARY MOVEMENT RANGES OF MOTION.. C-1

PART II AN EXPERIMENTAL EVALUATION OF SELECTED REWARMING THERAPIES FOR TREATMENT OF PROFOUND ACCIDENTAL HYPOTHERMIA..

PART III AN EVALUATION OF HUMAN THERMAL MODELS FOR THE STUDY OF IMMERSION HYPOTHERMIA PROTECTION EQUIPMENT.....................

LIST OF FIGURES

		Page
Figure I-1(a)	WE1 - Bayley WeatherMate Plus	9
Figure I-1(b)	WE2 - Henderson Zip-On Exposure Suit	9
Figure I-1(c)	WE3 - Stearns Heavy-Duty Offshore Survival Suit	9
Figure I-1(d)	WE4 - White Stag Nylon-Two Wet Suit	9
Figure I-1(e)	WP1 - Henderson Prototype Jacket	9
Figure I-1(f)	WP2 - Medalist Ski Shorty	11
Figure I-1(g)	WP3 - Mustang U-VIC Thermofloat	11
Figure I-1(h)	WP4 - NADC Modified Wet Suit	11
Figure I-1(i)	WP5 - Stearns Windjammer Jacket	13
Figure I-1(j)	WP6 - Stearns Offshore Survival Jacket	13
Figure I-1(k)	WP7 - Texas Recreation Corporation Nylon-Covered PFD	13
Figure I-1(l)	D1 - Beaufort MK-10 British Immersion Coverall	13
Figure I-1(m)	D2 - NADC Goretex Experimental Coverall	15
Figure I-1(n)	D3 - U.S. Air Force Modified Anti-Exposure Assembly	15
Figure I-1(o)	DF1 - Bayley Exposure Suit	15
Figure I-1(p)	DF2 - Helly-Hansen Survival Suit	15
Figure I-1(q)	DF3 - S.I.D.E.P. Seastep Survival Suit	17
Figure I-1(r)	DA1 - ILC Industries Prototype Survival Suit	17
Figure I-1(s)	DA2 - Dr. Rentsch's Prototype Survival Suit	17
Figure I-2	Exemplary Rectal Temperature Response	30
Figure I-3	Estimated Survival Times for Average Men	49
Figure I-4	Metabolic Rate Response : Subject BS	51
Figure I-5	Metabolic Rate Response : Subject GE	52
Figure I-6	Selected Elementary Movements	58
Figure I-7	Fatigue Induction Measurement Sequence	74
Figure I-8	Test Article Buoyancy	106
Figure I-9	Aesthetic-Appeal Instruction Sheet	111
Figure I-10	Rating Sheet for Aesthetic-Appeal	112
Figure I-11	Wearer-Confidence Instruction Sheet	113
Figure I-12	Wearer-Confidence Rating Sheet	114

LIST OF TABLES

		Page
Table 1-1	Equipment Requested for Examination	5
Table 1-2	Assignments of Test Articles to Investigations	7
Table 1-3	Levels of Hypothermia	20
Table 1-4	Experiment Sample Sizes and Water Temperatures	22
Table 1-5	Descriptions of Cold-Immersion Subjects	23
Table 1-6	Assignment of Cold-Immersion Subjects to Test Articles	24
Table 1-7	Results of Cold-Immersion Experiments	31
Table 1-8	Significance of Indices for Predicting Cooling Rates	34
Table 1-9	Cooling-Rate Predictor Models	37
Table 1-10	Cooling-Rate Estimates (Experiment Water Temperatures)	38
Table 1-11	Survival-Time Estimates (Experiment Water Temperatures)	41
Table 1-12	Ratios of Cooling Parameters From Mathematical Model	45
Table 1-13	Cooling Parameters Estimated for 1.7°C Water	46
Table 1-14	Survival-Time Estimates in 1.7°C Water	48
Table 1-15	Elementary Movements Considered and Selected	57
Table 1-16	Descriptions of Mobility Reduction Subjects	62
Table 1-17	Sizes of Test Articles Used in Mobility-Reduction Investigation	63
Table 1-18	Subjective Scoring of Mobility Reduction	65
Table 1-19	Summary of Movement Reductions: Means and (S.E.M.)'s in Degrees	67
Table 1-20	Descriptions of Fatigue Induction Subjects	71
Table 1-21	Sizes of Test Articles Used in Fatigue-Induction Investigation	72
Table 1-22	Test Conditions for Test Articles	73
Table 1-23	Weights of Test Articles	73
Table 1-24	Percent Heart-Rate Increases for the Three Experimental Exercises	77
Table 1-25	Temperature Increases for the Three Experimental Exercises	78
Table 1-26	Weighting Factors for the Five Activity Models	79
Table 1-27	Weighted Mean Percent Increases in Heart Rate	80
Table 1-28	Ranking of Test Articles by Mean Percent Heart Rate Increase for Five Activity Models	81

Table I-29 Comparisons Among Mean Heart-Rate Increases for the Test Subjects.................... 83

Table I-30 Increases in Weighted Average Skin Surface Temperature.................... 84

Table I-31 Comparisons Among Mean Surface Temperature Increases for the Test Subjects.................... 85

Table I-32 Description of Donning Investigation Subjects.................... 88

Table I-33 Assignment of Subjects to Test Articles (Donnings on Land).................... 89

Table I-34 Assignment of Subjects to Test Articles (Donnings in Water).................... 91

Table I-35 Times Required for Donnings on Land.................... 93

Table I-36 Comparisons Among Donnings Without Practice on Land.................... 95

Table I-37 Comparisons Among Donnings with Practice on Land.................... 96

Table I-38 Specific Difficulties in Donnings Without Practice on Land.................... 97

Table I-39 Times Required for Donnings in Water.................... 98

Table I-40 Comparisons Among Donnings Without Practice in Water.................... 98

Table I-41 Comparisons Among Donnings With Practice in Water.................... 99

Table I-42 Specific Difficulties in Donnings Without Practice in Water.................... 99

Table I-43 Buoyancy of Test Articles.................... 107

Table I-44 Descriptions of Aesthetic-Appeal/Wearer-Confidence-Investigation Subjects.................... 109

Table I-45 Aesthetic-Appeal Evaluation Results.................... 116

Table I-46 Wearer-Confidence Evaluation Results.................... 117

Table I-47 Comparisons Among Aesthetic-Appeal Scores.................... 118

Table I-48 Comparisons Among Wearer-Confidence Scores.................... 119

Table I-49 Summary of Results.................... 129

EXPERIMENTAL EVALUATIONS OF SELECTED IMMERSION HYPOTHERMIA PROTECTION EQUIPMENT

for

UNITED STATES COAST GUARD
U. S. Coast Guard Headquarters
Contract No. DOT-CG-72074-A
Task Number 3

Final Report, Part I

from

Clemson University

by

R. M. Harnett, Ph.D., E. M. O'Brien, Ph.D.,
F. R. Sias, Ph.D., and J. R. Pruitt, M.D.

October 12, 1979

1.0 INTRODUCTION

1.1 Background

The selection of equipment to provide protection from hypothermia during accidental immersion in cold water is difficult not only because the ability of the equipment to prolong life is difficult to assess, but also because there may be several additional attributes of the equipment which are variously important to different potential users. Merchant mariners or commercial fishermen require equipment which can be donned quickly in the event of an accident which necessitates prolonged survival in cold water. Aviation personnel who routinely fly over cold water may require equipment which can be worn for several hours at a time in warm air while they perform their various functions in the aircraft. Because they often are equipped with electronic devices which render them easy to locate by search and rescue teams, the aviators may not require protection during prolonged exposure (many hours). Some aviators, such as tactical aircraft crews or even search and rescue crews, may also place considerable demands

on their protection equipment to be quickly donned. Deck crewmen on boats and workers on offshore oil platforms may require equipment that can be used in a constant-wear mode but which will not interfere with their ability to perform their duties either directly by reducing their mobility or indirectly by inducing exceptional fatigue. There are other equipment performance attributes which are important in making selection decisions for equipment to be used by different groups with different requirements. This study was formulated to provide an evaluation of selected attributes for state-of-the-art equipment relevant to such selection decisions for merchant mariners, Coast Guard operational personnel and recreational boaters.

1.2 Objectives

The specific objectives of this study were to select hypothermia protection devices (test articles) representing the state-of-the-art in fundamentally different design approaches and to evaluate the following attributes as appropriate.

1. cold protection effectiveness
2. mobility reduction attendant to usage
3. propensity to induce fatigue and overheating
4. ease of donning (on land and in water)
5. buoyancy
6. aesthetic appeal and wearer confidence
7. fire resistance
8. reliability

The cold-protection effectiveness was evaluated through in vivo cold-immersion testing with volunteer test subjects. The results of this testing were expressed in terms of estimated survival times in 1.7°C (35°F) water. The mobility reduction and fatigue induction investigations were intended to address the feasibility of using certain devices in a constant-wear mode. Each donning trial (either on land or in water) was conducted twice -- once before and once after a leisurely equipment familiarization. This provides information on the potential value of equipment familiarization and donning practice with the various devices. The reliability investigation was based simply on observations of any deterioration in the conditions of test articles occurring during the performance of the other investigations.

1.3 Scope

The range of equipment to be considered for inclusion in this study was restricted to devices which are commercially available and to existing prototype devices. No new prototypes were developed for inclusion in the study. In addition, the selection of test articles was restricted to include in the study only one article representing each general type of equipment. The study was not intended to compare the products of different manufacturers which employ the same general design features.

The conduct of the cold protection effectiveness investigation was restricted to be based on data which could be obtained from safe, in vivo, cold-immersion experiments using human subjects. Thus human responses to cold-immersion, while wearing the test articles, could be observed only over a narrow range of body core temperatures involving the mildest hypothermia. The estimation of survival times associated with the test articles was, of necessity, based on extrapolations of observations made in mild hypothermia.

2.0 SELECTED TEST ARTICLES

2.1 Selection Procedure

The selection of articles to be included in the study was conducted in two stages. The first stage of activity led to the acquisition of candidate test articles. In the second stage, these were physically examined by a panel of concerned individuals including Coast Guard personnel and members of the research team. The panel evaluated the candidate test articles and made final selections of those to be included in the various investigations.

The objective of the first stage of activity was to identify as many candidate test articles as possible. For purposes of this initial review, a device was regarded as a candidate if it exhibited the potential to provide protection during cold-immersion for either merchant mariners, military crewmen (boat or aircraft) or recreational boaters. No screening was done on the basis of attributes other than potential for cold-immersion protection.

The basis for the first stage review was largely vendor publications. This literature was obtained through direct mail solicitations addressed to the suppliers listed in Appendix A. A few of them did not respond but the majority did, providing catalogs and other materials describing their products. This literature was generally descriptive but was not sufficiently detailed to support selections of test articles to be included in the study. It was used to support a gross screening of the equipment in which items that warranted more detailed examination were identified. These items were requested from the manufacturers or suppliers in order that they be studied for possible inclusion in the study. Table I-I lists the items which were requested and indicates those which were received and reviewed for possible inclusion in the study. The acquisition of these candidate test articles culminated the first stage of the selection process.

The final selection of test articles was performed by a panel composed of representatives of the Coast Guard Office of Research and Development, Office of Merchant Marine Safety,Office of Operations, and the research team. The candidate test articles were presented to the panel and verbal descriptions of the important design features were provided. The panel

TABLE I-1
EQUIPMENT REQUESTED FOR EXAMINATION

Manufacturers/ Suppliers	Suit (Model-Number)	Received and Reviewed	Selected
Bayley	Exposure Suit - neoprene foam	Yes	Yes
	Exposure Suit - PVC foam	Yes	Yes
	WeatherMate Plus	Yes	Yes
Beaufort	MK-10 British Immersion Coverall	Yes	Yes
DUI	Abandon Ship Suit	No	-
	Anti-Exposure Work Suit	No	-
	Super Polar Bear Suit	No	-
Dive N'Surf	Body Glove Wet Suit	Yes	No
Extrasport	One-Piece Action Suit	No	-
Fitz-Wright	Anti-Exposure Suit	Yes	No
Helly-Hansen	Survival Suit (D-600-0)	Yes	Yes
	Divers One-Piece Suit (F.351)	No	-
	Commodore Floating Jacket (D-303)	Yes	No
Henderson	Zip-On Exposure Suit (2080-4)	Yes	Yes
	Dry Suit (2021)	Yes	No
	Prototype Jacket	Yes	Yes
ILC Industries	Prototype Survival Suit	Yes	Yes
Imperial	Survival Suit (1409)	Yes	No
	Wet Work Suit (1407 JP)	Yes	No
Jeltek	Flotation Jacket (2470)	Yes	No
Medalist	Ski Shorty (7010)	Yes	Yes
Mustang	U-VIC Thermofloat (1661)	Yes	Yes
	Survival Suit (175)	Yes	No
	Survival Suit (9450/1)	No	-
	Floater Jacket (101)	No	-
NADC	Modified Wet Suit (CWU-33/P)	Yes	Yes
	Coveralls (CWU-27/P)	Yes	Yes
	Anti-Exposure Coverall (CWU-21/P)	Yes	No
	Anti-Exposure Coverall Liner (CWU-23/P)	Yes	No
	Goretex Experimental Coverall	Yes	Yes
	Coveralls (CWU-48/P)	Yes	No
	Coast Guard Jacket	Yes	No
Dr. S.B.Rentsch,Jr.	Modified Mark VII S.E.I.S.	Yes	Yes
S.I.D.E.P.	"Seastep" Survival Suit	Yes	Yes
Stearns	Windjammer Jacket (FJ-55)	Yes	Yes
	Flotation Jacket and Pants (FJ-55 J&P)	Yes	No
	Offshore Survival Jacket (FS-500)	Yes	Yes
	Sans-Souci PFD (SSV-70)	Yes	No
	Ship or Shore PFD (FV-105)	Yes	No
	Offshore Survival Suit (FS-70)	Yes	No
	Heavy-Duty Offshore Survival Suit (FS-71)	Yes	Yes
	Survival Jacket (FS-505)	Yes	No
	Flite Suit	Yes	No
Texas Recreation Corp.	Vinyl-Coated PFD	Yes	No
	Nylon-Covered PFD	Yes	Yes
Undersea Systems, Inc.	Variable Volume Dry Suit(ART.NR.3000)	No	-
	Variable Volume Dry Suit(ART.NR.3003)	No	-
	Thermal Underwear (ART.NR.3141)	No	-
U. S. Air Force	Modified Anti-Exposure Coverall(CWU-21/AP)	Yes	Yes
White Stag	Nylon Two Wet Suit	Yes	Yes

discussed the merits of obtaining data from the various investigations on each of the suits. Consensus opinions regarding the desirability of including each suit were developed by the panel. The suits which were selected to be included in one or more of the investigations are indicated in Table I-I.

This general procedure was applied to essentially all of the suits listed in Table I-I. However, there were some exceptions. The Beaufort MK-10, ILC Industries prototype, all suits supplied by NADC, the S.I.D.E.P. Seastep and the Air Force CWU-21/AP were unavailable for review at the time of the panel meeting. Selections were made by the panel on the basis of general descriptive information available to them. In addition the Dive N' Surf Body Glove and the Stearns Flite Suit were not decided on by the panel. These suits were identified later and were examined by the project director and the technical monitor. It was decided that they were not sufficiently different from suits already included in the study to warrant their addition to the group of test articles.

The specific assignments of the selected test articles to the various investigations included in this study are shown by x's and numbers in Table I-2. The numbers indicate that Dr. S. B. Rentsch's prototype was cold-immersion tested in two conditions (with and without reclamation of respiratory heat loss) while the other articles were tested in one condition. The assignment shown in Table I-2 is the final one which resulted from the initial panel meeting and a number of subsequent revisions which were coordinated through the project monthly progress reports. One of the test articles indicated in Table I-I to have been selected does not appear in Table I-2. The coveralls (CWU-27/P) were used as an outer garment worn over the Medalist Ski Shorty (short wet suit).

2.2 Descriptions of the Test Articles

The test articles considered in this study may be categorized by general design approach into the following five groups.

1. Wet suits covering entire body (WE)
2. Wet suits covering partial body (WP)
3. Dry suits with little intrinsic insulation (D)
4. Dry suits with foam-rubber insulation (DF)
5. Dry suits with air-space insulation (DA)

TABLE 1-2
ASSIGNMENTS OF TEST ARTICLES TO INVESTIGATIONS

TEST ARTICLES	Cold Protection	Mobility Reduction	Fatigue Induction	Donning In Water	Donning On Land	Buoyancy	Fire Resistance	Aesthetic Appeal	Reliability
Bayley Exposure Suit (neoprene foam)					x	x	x	x	x
Bayley Exposure Suit (PVC foam)	1				x	x		x	x
Bayley Weather Mate Plus	1	x	x	x	x	x	x	x	x
Beaufort MK-10 British Immersion Coverall		x	x		x	x	x	x	x
Helly-Hansen Survival Suit (D-600-0)	1	x	x		x	x		x	x
Henderson Zip-On Exposure Suit (2080-4)	1	x	x	x	x	x	x	x	x
Henderson Prototype Jacket	1	x	x	x	x	x	x	x	x
ILC Industries Prototype Survival Suit	1	x	x		x	x	x	x	x
Medalist Ski Shorty (7010)	1	x	x	x	x	x	x	x	x
Mustang U-VIC Thermofloat (1661)	1	x	x	x	x	x	x	x	x
NADC Goretex Experimental Coverall	1	x	x		x	x	x	x	x
NADC Modified Wet Suit (CWU-33/P)		x	x		x	x	x	x	x
Dr. S. B. Rentsch's Prototype Survival Suit	2					x		x	x
S.I.D.E.P. Seastep Survival Suit	1				x	x		x	x
Stearns Windjammer Jacket (FJ-55)	1	x	x			x		x	x
Stearns Offshore Survival Jacket (FS-500)	1	x	x	x	x	x	x	x	x
Stearns Heavy-Duty Offshore Survival Suit (FS-71)	1	x	x	x	x	x	x	x	x
Texas Recreation Corp. Nylon-Covered PFD	1					x		x	x
U.S. Air Force Modified Anti-Exposure Assembly (CWU-21/AP)	1	x	x		x	x	x	x	x
White Stag Nylon-Two Wet Suit (3/16")		x	x	x	x	x	x	x	x

The following paragraphs present descriptions of the test articles grouped into these categories. The ancillary equipment with which they were tested is also described.

Two ensembles of ancillary equipment were standardized for use in testing certain of the test articles. One, which will be referred to as "standard work/recreation clothing", consists of denim jeans, a light-weight, long-sleeved cotton shirt, cotton undershorts and T-shirt, cotton athletic socks and low-top canvas sneakers. The other, referred to as "standard ancillary aviator's ensemble", consists of one suit of nomex underwear and undershirt (CWU-43/P and CWU-44/P), one pair of cotton athletic socks, low-top canvas sneakers, and an aviator's water wings flotation device (SRU-21 and LPU-10).

2.2.1 Wet Suits Covering Entire Body

Bayley WeatherMate Plus (WE1)

The WeatherMate Plus, shown in Figure 1-1(a), is a two-piece suit constructed of neoprene foam rubber. The jacket features a deployable diaper-like closure at the groin, a hood formed from the collar by closing a zipper and an orally-inflated flotation bladder located mainly in the upper shoulders area. Cinching, belt-type closures are provided at the wrists and ankles. This suit was tested over the standard work/recreation clothing.

Henderson Zip-On Exposure Suit (WE2)

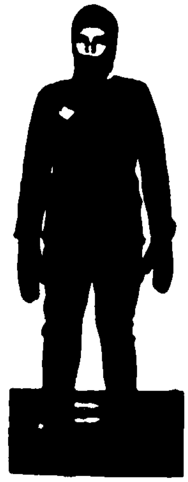
This exposure suit, shown in Figure 1-1(b), is essentially a 3/16 inch neoprene wet suit with zippered gussets provided on the arms, legs, hips and torso to facilitate donning and to permit tightening the fit of the suit in the event of inadvertent entry of cold water. Accessories include a hood, three-finger mitts and hard-sole booties. Velcro closures are provided at the wrists and ankles to retard the entrance of outside water into the puckers caused by closing the zippered gussets. This suit was worn over undershorts only.

Stearns Heavy-Duty Offshore Survival Suit (WE3)

This survival suit, shown in Figure 1-1(c), is a one-piece jumpsuit, lined with PVC foam rubber of varying thickness (thicker on torso than arms). A hood attaches to the suit by two snaps. Zippered closures are provided at the wrists and ankles. Supplemental flotation is provided by an orally-inflated flotation bladder located in the upper chest area. This suit was tested over the standard work/recreation clothing.

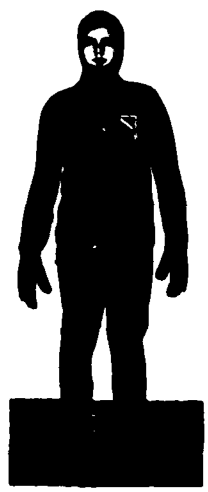
FIGURE 1-1

(a) WE1 - Bayley WeatherMate Plus



(b) WE2 - Henderson Zip-On Exposure Suit

(c) WE3 - Stearns Heavy-Duty Offshore Survival Suit



(d) WE4 - White Stag Nylon-Two Wet Suit

White Stag Nylon-Two Wet Suit (WE4)

This standard wet suit, shown in Figure 1-1(d), is constructed from 3/16 inch neoprene rubber (Rubatex 1400). Accessories include a hood, 5-finger mitts and soft-sole booties. Zippered closures are provided at the wrists and ankles. This suit was tested over undershorts only.

2.2.2 Wet Suits Covering Partial Body

Henderson Prototype Jacket (WP1)

This jacket, shown in Figure 1-1(e), is constructed of neoprene foam rubber of varying thickness. An integral hood stows under the collar. Zippered gussets are provided on the arms and torso. Velcro closures are provided at the wrists. A beaver tail, slightly larger than on a standard wet suit closes the bottom of the jacket. It was tested over the standard work/recreation clothing and with a small kapok Type II Mae West flotation aid.

Medalist Ski Shorty (WP2)

This suit, shown in Figure 1-1 (f), is a one-piece short wet suit constructed of nylon-faced neoprene rubber 1/8 inch thick. It was tested in conjunction with a wet suit hood (White Stag 3/16 inch), light weight flight coveralls (CWU-27/P), cotton athletic socks, canvas sneakers and the water wings flotation device (SRU-21 and LPU-10). The short wet suit was worn over undershorts only.

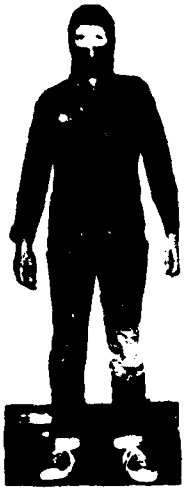
Mustang U-VIC Thermofloat (WP3)

This jacket, shown in Figure 1-1(g), is lined with PVC foam rubber of varying thickness. Recessed knit cuffs provide some protection from outside water entry. A deployable diaper-like device provides groin protection and closes the bottom of the jacket. A thin hood stows inside the collar. This jacket was tested over the standard work/recreation clothing.

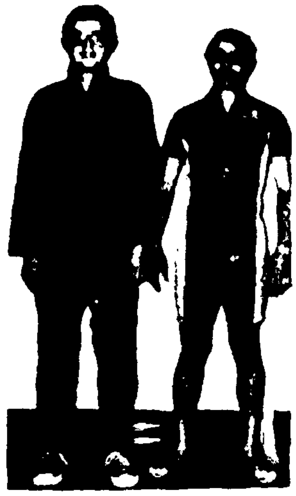
NADC Modified Wet Suit (WP4)

This suit, shown in Figure 1-1(h), is a combination of a flight suit and a short-sleeved, one-piece wet suit. The wet suit construction is of neoprene rubber and features zippered closures at the ankles. Fittings and tubing are provided in the suit to allow it to be attached to a forced-air cooling system to remove excess body heat while in a dry environment. This capability was not exercised during testing. This suit was tested with one suit of nomex underwear, athletic socks and sneakers.

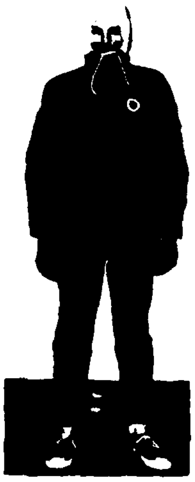
FIGURE I-I (Continued)



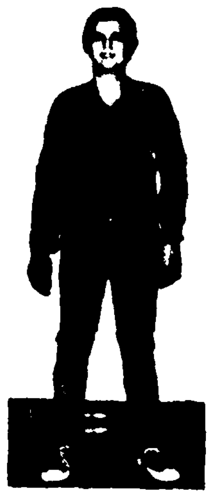
(e) WPI - Henderson Prototype Jacket



(f) WP2 - Medalist Ski Shorty



(g) WP3 - Mustang U-VIC Thermofloat



(h) WP4 - NADC Modified Wet Suit

Stearns Windjammer Jacket (WP5)

This jacket, shown in Figure I-I(1), is lined with PVC foam rubber of varying thickness. Recessed knit cuffs provide some protection from outside water entry. A thin hood stows inside the collar. This jacket was tested over the standard work/recreation clothing.

Stearns Offshore Survival Jacket (WP6)

This jacket, shown in Figure I-I(j), is lined with PVC foam rubber of varying thickness. An additional inner liner of 1/8 inch neoprene foam may be closed after entering the water providing additional protection to the torso. This liner is closed at the bottom by a narrow beaver tail. Recessed knit cuffs provide some protection from outside water entry. Additional elastic, wrap around closures are provided at the wrists. An insulated hood is an integral part of this jacket. This jacket was tested over the standard work/recreation clothing.

Texas Recreation Corporation Nylon-Covered PFD (WP7)

This flotation vest, shown in Figure I-I(k), is lined with unicellular foam rubber. The design features no openings through which water could pass except the front, which is closed by three buckles. Selecting for snug fit reduces the ability of water to enter around the vest. This vest was tested over the standard work/recreation clothing.

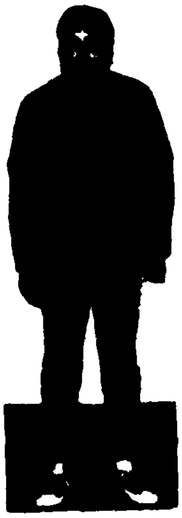
2.2.3 Dry Suits with Little Intrinsic Insulation

This group of test articles share the property that they are generally constructed from thin material which seeks to provide a water barrier during immersion. This allows one to achieve cold protection by imposing beneath the suit a garment (e.g., nomex, waffle-weave underwear) which will immobilize an air layer.

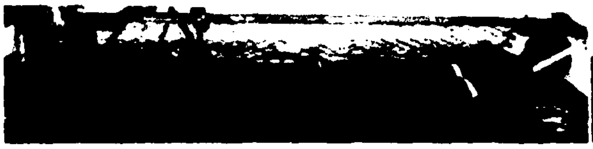
Beaufort MK-10 British Immersion Coverall (D1)

The Mark 10 immersion coverall, shown in Figure I-I(l), is a one-piece suit with integral foot coverings which can be worn under flight boots. It is constructed of double-layered ventile fabric. Ventile fabric is designed to permit the elimination of waste heat by passing water vapor when in the dry, but to provide a water barrier during immersion because of changes that occur in the fabric. The coverall is closed by means of a single waterproof zipper which closes from the right shoulder to the left hip. Water is also excluded from the suit by elastic seals at the neck and wrists. The suit was tested with one suit of nomex underwear and canvas sneakers.

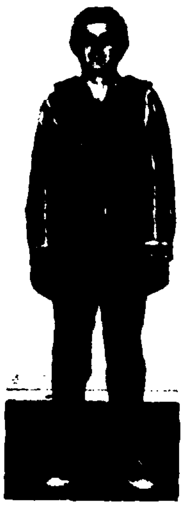
FIGURE I-1 (Continued)



(i) WP5 - Stearns Windjammer Jacket



(j) WP6 - Stearns Offshore Survival Jacket



(k) WP7 - Texas REcreation Corporation
Nylon Covered PFD

(l) DI - Beaufort British Immersion
Coverall

NADC Goretex Experimental Coverall (D2)

This experimental coverall, shown in Figure I-1(m), was constructed of a light, canvas-type nomex to which "goretex" had been lalmnated on the inside. The theory of this construction is that it permits the elimination of waste heat in the dry since goretex is permeable to water vapor while providing a water barrier during immersion because of changes that occur in the goretex. The coverall has integral foot coverings which could be worn under flight boots. The coverall is closed by means of a single waterproof zipper which closes from the left shoulder to the groin. Water is also excluded from the suit by elastic seals at the neck and wrists. The suit was tested with the standard ancillary aviator ensemble.

U. S. Air Force Modified Anti-Exposure Assembly (D3)

This assembly, shown in Figure I-1(n), is a modification of the CWU-21/P. It is constructed of single-layered ventile fabric which is designed to permit the elimination of waste heat, by passing water vapor when in the dry but to provide a water barrier during immersion because of changes that occur in the fabric. The assembly has integral foot coverings which can be worn under flight boots. The coverall is closed by means of a single waterproof zipper which closes from the groin to the throat. Water is also excluded from the suit by elastic seals at the neck and wrists. The suit was tested with the standard ancillary aviator ensemble.

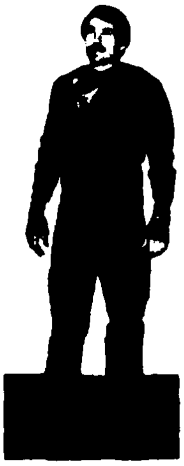
2.2.4 Dry Suits With Foam Rubber Insulation

The test articles in this category share the features that they seek to keep the occupant dry and warm. Thermal insulation is provided in the form of a foam-rubber-stabilized layer of air.

Bayley Exposure Suit (DF1)

This exposure suit, shown in Figure I-1(O), was tested in two types of foam rubber (neoprene and PVC) each 3/16 inch thick. The suit includes integral head, hand and foot protection and will accommodate shoes inside. The suit is closed by a single waterproof zipper which closes from the groin to the chin. The intrinsic buoyancy of the suit is augmented by an orally-inflated "pillow" which attaches to the upper back area by two short zippers. Water is excluded from the suit by a soft rubber seal around the wearer's face. Flotation attitude may be controlled somewhat by expelling

FIGURE I-I (Continued)




(m) D2 - NADC Goretex Experimental Immersion Coverall


(n) D3 - U. S. Air Force Modified Anti-Exposure Assembly


(o) DFI - Bayley Exposure Suit


(p) DF2 - Helly-Hansen Survival Suit

excess air from the legs of the suit through "valves" located on the toe area of each leg. This suit was tested over the standard work/recreation clothing.

Helly-Hansen Survival Suit (DF2)

This suit, shown in Figure I-1(p), utilizes foam rubber to impede conductive heat transfer and has a metalized foil layer between the outer material and the foam rubber to impede the loss of heat by radiation. The suit includes integral head and foot protection and will accommodate shoes inside. The suit is closed by a single waterproof zipper which closes from the groin to the chin. Water is excluded from the suit by neoprene rubber seals at the wrists and around the wearer's face. This suit was tested over the standard work/recreation clothing. The hands were protected by 3/16 inch neoprene three-finger wet-suit mitts.

S.I.D.E.P. Seastep Survival Suit (DF3)

This suit, shown in Figure I-1(q), is constructed of 5 mm thick closed-cell, nylon-lined neoprene rubber. The suit includes integral head and foot protection. Integral five-finger hand coverings are also provided but are constructed of much thinner material. The entrance is a tubular attachment joining the suit at the shoulders. It is closed by a zipper but the waterproof seal of the entrance is provided by rolling it and hooking it to a metal ring on the chest. This ring also serves as the focus for a built-in harness facilitating retrieval by winch from the water. Intrinsic flotation is augmented by an inflatable, front-mounted bladder. The suit does not accommodate shoes inside. It was tested over the standard work/recreation clothing, less the sneakers.

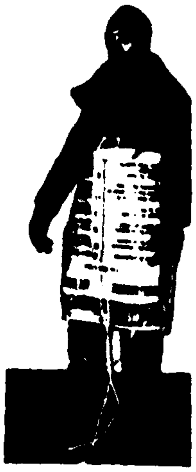
2.2.5 Dry Suits With Air-Space Insulation

The suits in this group share the feature that they seek to provide cold protection through an air-space which is contained in and controlled (for thickness) by an inflatable, air-tight bladder. This contrasts with the dry, foam suits which immobilized an air-space in closed-cell foam rubber.

ILC Industries Prototype Survival Suit (DA1)

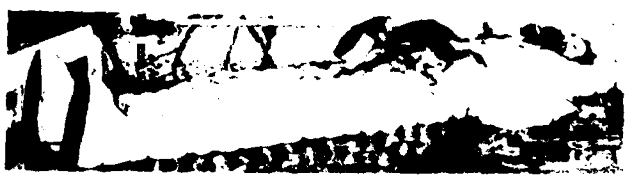
This prototype suit, shown in Figure I-1(r), consists of two main components. An outer shell to which goretex has been laminated permits the release of water vapor in the dry but provides a water barrier during immersion. Inside this

FIGURE 1-1 (Continued)



(q) DF3 - S.I.D.E.P. Seastep Survival Suit

(r) DA1 - ILC Industries Prototype Survival Suit



(s) DA2 - Dr. Rentsch's Prototype Survival Suit

shell is an inflatable bag which surrounds the entire body. The two layers of the bag are heat sealed together in round patches at regular intervals to control the thickness of the air layer when fully inflated. The centers of the heat sealed patches were removed to provide paths for water vapor to escape the body carrying excess body heat with it. Integral protection is afforded the feet. An inflatable hood was also attached to the back of the suit. The hands are protected by separate inflatable mitts. Inflating seals are provided at the neck and wrists. The suit has fittings and tubing to allow it to be connected to a forced-air cooling system to remove excess body heat while in a dry environment. This capability was not exercised during testing. The outer shell is closed by a single zipper (not waterproof) which closes from the groin to the neck. A separate watertight closure made of heavy plastic and similar to the closures of a zip-lock bag is provided inside this zipper. This suit was tested with the nomex underwear and cotton athletic socks. The air bag was orally inflated to the maximum extent possible.

Dr. Rentsch's Prototype Survival Suit (DA2)

This prototype suit, shown in Figure I-1(s), is a modified Beaufort Mark VII Submarine Escape and Immersion Suit. The prototype completely encloses the body (except for the hands) with respiration being accomplished through gas exchange orifices in the bicurved face plate. A separate mouth port is provided for issuing distress calls (e.g., by blowing a whistle). The suit is an inflatable insulation bladder surrounding the body. A separate inflatable Mae West-like flotation bladder is provided. The two layers of the insulation bladder are sealed together at regular intervals (giving the dimpled appearance) to control the thickness of the air layer when the bladder is fully inflated. Integral air-space protection is provided the feet and head. The hands are protected by inflatable mitts. Elastic seals are provided at the wrists. The suit closes by a single waterproof zipper extending from the groin to the neck and then around the right side of the head to a terminal position at the top, left side of the head. Exhaled gasses are shunted down a plastic tube to the inside of the suit in an attempt to reclaim respiratory heat losses. Opening the mouth port effectively eliminates this heat reclamation aspect of the suit. This suit was tested over the standard work/recreation clothing with the air bladder orally inflated to the maximum extent possible. It was cold-immersion tested in two conditions: mouth port closed and mouth port open. This was done to obtain an indication of the potential usefulness of respiratory heat reclamation.

3.0 COLD-PROTECTION EFFECTIVENESS INVESTIGATION

3.1 Objectives

The objective of the cold-protection effectiveness investigation was to establish a quantitative measure of the effectiveness with which each test article selected for this investigation protects victims of accidental immersion from potentially-lethal losses of body heat. To facilitate the meaningful interpretation of these quantitative results they were expressed in terms of survival-time estimates. To facilitate comparisons among the test articles the survival times were estimated to correspond to immersion in 1.7°C (35°F) water. It was known that several of the test articles could not be tested in water that cold, due to test subject discomfort and the risk of damage to peripheral tissues. Therefore, it was anticipated that the survival-time estimates for these test articles would have to be established using an analytically-based adjustment to estimates associated with warmer water.

It was desired that the analysis of the experiment results should provide the capability to estimate survival time for individuals with selected physical structures (morphologies). This capability was needed to determine the survival times afforded individuals with morphologies different from the average. It was also needed to permit comparisons among the survival times of the test articles for selected morphologies when the articles were tested by different test subjects. Achieving this capability required that a quantitative measure of morphology be internalized into the analysis methodology. It was hoped that this analysis approach would also serve to reduce unexplained (random) variation in the results.

3.2 Methodology

The estimation of survival times was, of necessity, based on extrapolations of the core cooling observed in volunteer test subjects wearing the suits during cold-water immersions in which only mild hypothermia was induced. As indicated in Table 1-3, the determination of a lethal level of core cooling (measured rectally) is nontrivial. It was for this reason that Hayward, et al., (1978) parameterized on its value using 27, 30 and 33°C. For present purposes core cooling is assumed to be lethal at 30°C. It is at this level that cold-induced physical and mental debilitation remove the immersion victim's ability to participate meaningfully in the

TABLE I-3

LEVELS OF HYPOTHERMIA[†]

°F	°C	
99.6	37.6	"Normal" Rectal Temperature
96.8	36	Increased Metabolic Rate in attempt to balance heat loss
95.0	35	Shivering maximum at this temperature
93.2	34	Patients usually responsive and normal blood pressure
91.4	33	<u>SEVERE HYPOTHERMIA BELOW THIS TEMPERATURE</u>
89.6	32	Consciousness clouded — Pupils dilated; most shivering ceases
87.8	31	Blood Pressure difficult to obtain — Pupils dilated; most shivering ceases
86	30	Progressive loss of consciousness Increased muscular rigidity Slow pulse and respiration
85.2	29	
82.4	28	Cardiac arrhythmia develops Ventricular fibrillation may develop if heart irritated
80.6	27	Voluntary motion lost along with pupillary light reflex, deep tendon and skin reflexes - appear dead
78.8	26	Victims seldom conscious
77.0	25	Ventricular fibrillation may appear spontaneously
75.2	24	Pulmonary Edema develops
73.4	23	Maximum risk of fibrillation
71.6	22	
69.8	21	
68.0	20	Heart Standstill
66.2	19	
64.4	18	Lowest <u>Accidental</u> Hypothermic patient with recovery
62.6	17	ISO-ELECTRIC EEG
48.2	9	Lowest Artificially Cooled Hypothermic patient with recovery

† From Harnett, et al., (1979)

preservation of his life. Table I-3 makes clear that the cold, in and of itself, is not necessarily lethal at 30°C. However, survival below this level depends upon exogenous support of flotation and freeboard for breathing passages. While many of the test articles considered in this study provide abundant buoyancy, none is intrinsically capable of guaranteeing breathing passage freeboard. Most could however be supplemented with flotation devices with sufficient righting moment to support respiratory ventilation. However, at present the use of flotation devices with this intrinsic capability is not required by all individuals at risk of cold-immersion and therefore may not be relied upon to extend survival beyond the point of physical and mental debilitation.

Design of the Experiment

The basic experiment plan called for obtaining 5 replications of cold immersions with each of the 17 test articles (Rentsch's prototype twice) indicated for the cold-protection effectiveness investigation in Table I-2. These were to be performed in such a way that each test article was worn by test subjects exhibiting a reasonable range of physical characteristics. Because a study of rewarming therapies (described in Part II of this report) was integrated with this suit investigation and additional rewarmings were desired, additional experiments were obtained with some of the suits extending their sample sizes to 6. Table I-4 shows the sample sizes which were obtained with each suit and the means and standard deviations of the temperatures of the water and air in which the experiments were done. Two target temperatures were used 1.7°C (35°F) and 11.8°C (53.2°F). The warmer water temperature was selected to match that used by Hayward, et al.(1978) and to preclude injury to unprotected or lightly protected peripheral tissues.

Table I-5 presents the physical characteristics of the 19 male test subjects who participated in this investigation. The subjects who tested each of the test articles and the sizes they wore are indicated in Table I-6. Because of the special nature of the comparison to be made between the two conditions with DA2 (mouth port open and closed), special emphasis was placed on arranging the test subject - test article assignments to involve the same subjects in both experiments with this suit.

This repeated use of test subjects was not possible to accomplish overall. The volunteers were free to withdraw from participation in the project at any time - a right some of them exercised; e.g., KC, JH, CM, MO, TP, PS and BS.

TABLE I-4
EXPERIMENT SAMPLE SIZES AND WATER TEMPERATURES

Suit Code	Suit Description	Number of Replications	Water Temperature (°C)		Air Temperature (°C)	
			Mean	S.D.	Mean	S.D.
WE1	Bayley WeatherMate Plus	5	11.8	0.1	21.3	0.5
WE2	Henderson Zip-On Exposure Suit	5	1.9	0.3	21.4	1.2
WE3	Stearns Heavy-Duty Offshore Survival Suit	5	12.1	0.4	21.4	0.7
WP1	Henderson Prototype Jacket	5	12.0	0.3	21.1	0.0
WP2	Medalist Ski Shorty	5	11.8	0.1	21.8	0.9
WP3	Mustang U-VIC Thermofloat	5	11.8	0.0	20.6	1.0
WP5	Stearns Windjammer Jacket	6	12.0	0.3	21.4	0.8
WP6	Stearns Offshore Survival Jacket	5	11.8	0.1	21.0	0.2
WP7	Texas Recreation Corp. Nylon-Covered PFD	6	11.8	0.1	21.6	1.1
D2	NADC Goretex Experimental Coverall	6	11.9	0.1	22.0	1.6
D3	U. S. Air Force Modified Anti-Exposure Assembly	5	11.8	0.0	22.2	1.2
DF1	Bayley Exposure Suit (PVC foam)	5	2.0	0.3	20.8	0.6
DF2	Helly-Hansen Survival Suit	6	1.9	0.5	21.6	1.2
DF3	S.I.D.E.P. Seastep Survival Suit	5	1.9	0.4	21.3	1.8
DA1	ILC Industries Prototype	5	1.7	0.2	22.9	3.2
DA2	Rentsch's Prototype (mouth port closed)	5	1.9	0.3	22.7	1.3
DA2	Rentsch's Prototype (mouth port open)	5	1.7	0.2	22.6	3.3

TABLE I-5

DESCRIPTIONS OF COLD-IMMERSION SUBJECTS

Subject	Age	Height (cm)	Weight (kg)	Heath-Carter Somatotype Components *			Surface Area † (m^2)	Total Skinfold Thickness @ (mm)	Mean Reciprocal Skinfold Thickness @ (mm^{-1})
				I	II	III			
JC	21	182.0	88.2	4.0	6.0	1.5	2.11	37	.083
KC	21	185.0	85.4	3.5	4.0	2.0	2.13	31.7	.095
GE	23	182.9	65.5	2.0	4.0	4.5	1.86	21	.143
GF	23	178.2	67.3	2.5	4.0	3.5	1.85	26.5	.115
BH	23	178.9	82.7	4.5	4.0	1.5	2.03	43	.071
MH	25	182.7	64.1	1.5	2.5	5.0	1.83	18	.170
JH	21	170.3	70.4	4.0	5.5	1.5	1.82	36.7	.083
MK	22	183.0	75.9	2.5	5.0	3.0	1.98	26	.123
PK	21	183.9	91.4	4.5	6.0	1.5	2.16	41	.078
CM	21	186.6	70.2	2.5	3.0	4.5	1.95	25	.122
RM	24	168.3	63.6	4.0	5.0	2.5	1.73	37	.084
MO	21	180.0	76.4	3.5	6.5	2.5	1.96	33	.091
TP	25	185.2	76.4	3.0	3.5	3.5	2.02	29	.108
CR	19	180.4	69.3	2.0	4.0	3.5	1.90	22	.148
JR	21	178.5	60.9	3.0	3.0	4.5	1.78	30	.103
PS	19	179.2	75.4	3.0	4.5	2.5	1.95	31	.097
BS	21	187.1	71.4	2.5	4.0	4.5	1.96	27	.118
SW	22	177.5	66.3	3.0	4.0	3.5	1.82	28	.115
TW	23	177.0	74.5	4.0	4.0	2.0	1.92	38.2	.083
Averages	21.9	180.4	73.4	3.1	4.3	3.0	1.93	30.6	.107

* See Carter (1975)

† From Dubois Body Surface Chart prepared by Boothby and Sandiford (Mayo Clinic)

@ Skinfold thicknesses measured at tricep,subscapular and suprailiac with Lange Caliper.

TABLE I-6
ASSIGNMENT OF COLD-IMMERSION SUBJECTS TO TEST ARTICLES

TEST ARTICLES	TEST SUBJECTS																			Range of Total Skinfold Thickness (mm)
	JC	KC	GE	GF	BH	MH	JH	MK	PK	CM	RM	MO	TP	CR	JR	PS	BS	SW	TW	
WE1			M	M			M	M										M		21 - 36.7
WE2				M					L						M			M	L	26.5 - 41
WE3		M		M	M			M										M		26.5 - 43
WP1			M		L			M			M						M			21 - 43
WP2		L	M					M	L			M								21 - 41
WP3			S		M			M	L				M							21 - 43
WP5		M	S		M				M							M		S		21 - 43
WP6				S/M	L/E				L/E			S/M						S/M		26.5 - 43
WP7	L	L	M					M	L								M			21 - 41
D2	40		38	40						40		40					40			21 - 37
D3			M							M	M			M			M			21 - 37
DF1 (PVC)				X					X					X			X	X		22 - 41
DF2				M		M		M					M				M		M	18 - 38.2
DF3				M				M				M		M				M		22 - 33
DA1						X					X			X	X				X	18 - 38.2
DA2 (closed)						X					X			X	X				X	18 - 38.2
DA2 (open)						X					X			X	X				X	18 - 38.2

S = Small
M = Medium
L = Large
S/M = Small/Medium
L/E = Large/Extra Large
38 = Chest size (inches), length-regular
40 = Chest size (inches), length - long
X = Unsized prototype or one-size fits all

Furthermore, these subjects were simultaneously participating in the study of rewarming therapies in which their useful participation was limited to eight experiments. Therefore, they could not participate in more than eight cold-immersion suit experiments.

The plan for analyzing the experimental results was formulated to relieve the necessity for complete replication in testing each article with each subject. Survival-time predictions would be developed from regression-based relations which quantitatively predict cooling behavior in each particular suit as a function of the physical characteristics of a selected individual. A separate regression relation would be established for each suit from the cooling behavior observed during its [illegible]. The primary requirements of this approach to developing survival [illegible] are that a reasonable number of replications be performed [illegible] article and that each be tested by subjects representing the range of physical structures for which survival-time estimates are desired. Table I-6 indicates the range of total skinfold thickness (three sites: tricep, subscapular and suprailiac) exhibited by the subjects testing each article. The significance of this total skinfold thickness (which provides the basis for Heath-Carter Somatotype Component I) as a quantifier of physical structure is established in Section 3.4. The ranges in skinfold thickness shown in Table I-6 all contain the 30.6 mm value used as a quantitative descriptor for the "average" man. The use of a 30.6 mm total for an average man is based on the average of the 19 test subjects described in Table I-5 and its significance is also discussed in Section 3.4.

Experiment Protocol

The cold-immersion experiments were conducted [illegible] time, in a tank of refrigerated water between June 30, [illegible]. All were conducted beginning in the early afternoon (betwe[illegible] [illegible]ects were requested to report to the laboratory having had no alcohol [illegible]ication for 24 hours or food or tobacco for 2 hours. If there was doubt as to the proper size of a test article for a subject to wear, he was asked to try on the most likely sizes and the one affording the best fit was selected. After voiding his bladder and/or bowels, instrumentation was applied to the subject, including a rectal temperature probe; skin probes for great toe, thigh, groin, subscapular, bicep and forearm temperatures; ECG and

sphygmomanometer. Next the subjects donned clothing appropriate for the article they were to test that afternoon (either standard work/recreation clothing, nomex underwear and socks, or for WE2 and WP2 just undershorts). The subjects then began a 30-minute rest period which they spent reclined on a 4" foam rubber mattress and, depending upon their clothing, covered for thermal comfort. Following the 30-minutes of rest, measurements of their rate of oxygen uptake and the other parameters were recorded while the subjects were still reclined and resting. The subjects then donned the test article and entered the cold-immersion tank via a hydraulic chair lift. When testing wet-mode suits, a gradual entry into the water was permitted taking up to 4 or 5 minutes. This reduced the trauma of the entry and presumably the stressfulness of the exposure (although blood pressures of 160/100 mm Hg were not uncommon during the initial phase of the immersion). The immersion was regarded as initiated when the subject was immersed to waist level.

During the course of the immersion, temperatures were monitored continuously and recorded periodically with the sampling frequency being determined on the basis of the rates of changes of the parameters. Measurements of the rate of oxygen uptake were generally made at 1-hour intervals through the immersion plus an additional measurement was made just before removing the subjects from the cold water. Oxygen uptake measurements were not made in test article DA2 (open or closed).

The cold-immersion experiments could have been terminated on the basis of any one of the following criteria.

1. rectal temperature reduced by 2°C or to 35°C
2. any skin temperature reduced to 5°C
3. discretion of the test subject
4. discretion of the attending physician
5. discretion of the research team leader

In practice, the attending physician never found it necessary to terminate an immersion experiment, nor was one ever terminated because of excessively-cold skin.

The immersions were conducted in a steel tank containing water about 1.67 meters deep with surface of 1.83 by 3.05 meters. The water was agitated by a small air-powered turbulator (primarily intended to deice refrigeration coils and prevent thermal stratification of the water) and a 12-volt, DC-powered trolling motor (to prevent formation of thermal boundary layers around

the immersed subjects). An effective water velocity of 3 to 5 meters per minute was produced. This velocity is more than the 1.5 meters per minute shown by Baker (1979) to be required to effectively maximize convective heat losses due to relative motion of the water. No other provision was made to attempt to simulate effects of open water.

Throughout the immersion, the subject's position in the water was essentially that which resulted from the inherent flotation of the test articles. With some test articles this inherent flotation was augmented by inflating flotation bladders. This was the case for WE1, WE3, WP2, D2, D3, DF1, DA1 and DA2. Inflating the bladder accompanying DF3 had no effect on flotation attitude in the calm water in the immersion tank. Therefore, it was not inflated during the cold immersions. One test article (WP1) required supplemental flotation to provide reasonable breathing-passage freeboard during the immersion. This was provided by a kapok, Mae West Style Type II PFD which was selected because of its minimal interference with the thermal performance of the test articles.

Instrumentation

The instrumentation used to monitor temperature data in this study was all manufactured by Yellow Springs Instruments. Skin temperatures were measured with a Model 44TD, 12-channel monitor (50°C face sweep) using Model 409 probes (1.1 second time constant) taped to the skin. Rectal and esophageal temperatures were measured with a Model 46TUC, 6-channel monitor (11°C face sweep) using Model 401 probes (7.0 second time constant). The accuracy of temperature probes was verified, over the range of 12.6 to 37.8°C.

3.3 Results

The complete rectal temperature-immersion time profiles are shown graphically for each immersion of each test article in Appendix B. These graphs show the changes which occurred in rectal temperatures as functions of elapsed immersion time. The first step in analyzing these results is to adopt a general model of the cooling process.

Selecting a Model of the Cooling Process

Three considerations predominate the selection of a model of the cooling process.

1. The parameters of the model must be estimatable from the data obtained during the cold-immersion experiments.

2. The model should "fit" the observed data reasonably well.

3. The model should have some basis suggesting that extrapolations of the temperature response below levels seen experimentally are reasonable.

Of these three considerations, numbers 1 and 3 are very much more important than number 2. Consideration 3 will be addressed first.

There is little real evidence on which to base extrapolations of core temperatures for individuals protected by equipment of varying efficiencies. Alexander (1945) presents the time-rectal temperature profile of a prisoner murdered by cold-water immersion at Dachau concentration camp. The temperature reduction, once it began, occurred at an essentially constant rate (about 11°C/hr). One might expect that a well-protected immersion victim would cool, perhaps linearly, until at some point the gradient between the victim and the water is reduced sufficiently and the metabolic rate is increased sufficiently to collectively reduce the rate of cooling. This would produce a convexity (deceleration) in the cooling profile. One might also expect, based on the information in Table 1-3, that as the core temperature approaches 32°C, reduced capacity for shivering thermogenesis would increase the rate of cooling. This would produce a concavity (acceleration) in the cooling profile.

The problem of extrapolating the cooling response in the face of conflicting expectations is paralleled by another such extrapolation problem that is receiving intensive study at the present time. The problem is estimation of the carcinogenic/mutagenic response elicited by low-dose exposures to a variety of substances and radiations. The low level of the response at low doses and its delayed nature make the magnitude of the response extremely difficult to measure directly. The present approach is to measure the response (in laboratory animals or bacteria) at higher dosage levels, where the response can be accurately measured, and to estimate the low-dose response by extrapolation of the observations. As reported by Marshall (1979) the Committee on the Biological Effects of Ionizing Radiation (CBEIR) of the National Academy of Sciences worked for 2 years evaluating the various methods for estimating low-dose risk. After some strife, the majority of the committee reported in favor of basing risk estimates on what has come to be known as the "linear hypothesis". Marshall reports that the

CBEIR concluded, "There is no truly adequate basis for such estimation (of the effects of low-level radiation) but...regulatory decisions require a position on the estimation of risk...," and that a majority of the committee found the linear hypothesis, "least objectionable in the absence of clear evidence as to the shape of the dose-effect curve..."

This situation closely resembles the problem of extrapolating the cooling response. The determination of survival time requires an estimation methodology but there is no truly adequate basis for the estimation. The authors of this report agree with the majority of the CBEIR that a linear model is least objectionable in the absence of indications to the contrary.

A Linear Cooling Model

Figure 1-2 exemplifies the linear model adopted for developing survival-time estimates. The model entails three parameters: the maximum elevation in core temperature (T), the time at which this maximum elevation occurred (t), and the rate of cooling (r) that occurred after time t. The rate-of-cooling parameter is simply based on the slope between the observation at time t and the last observation recorded. The adoption of this particular linear model involved consideration 1 from the earlier list. A simpler, two-parameter model was considered first. The only parameters required to describe this simpler model are the time at which the change in rectal temperature returns to zero and the rate of cooling following this time. For these parameters to be estimable from the experimental observations (consideration 1), it is necessary that the change in rectal temperature must have returned to zero in each experiment. This was not the case as can be seen in Appendix B. Therefore the three-parameter linear model was adopted to describe the cooling process. It was dictated by considerations 1 and 3. Consideration 2, which may superficially seem important, did not enter into the selection of the model. Secton 3.5 presents a discussion of selected observations relating to consideration 2.

Experimental Observations

The results of the cold-immersion experiments are summarized, in terms of the linear-model parameters, in Table 1-7. The means and standard errors of the means are shown for each of the three parameters for each of the test articles. The t parameters have been presented in units of hours to facilitate later estimation of survival times in hours. It should be noted that the t's range over such small values (less than 0.59 hours) that they would not

FIGURE I-2
EXEMPLARY RECTAL TEMPERATURE RESPONSE

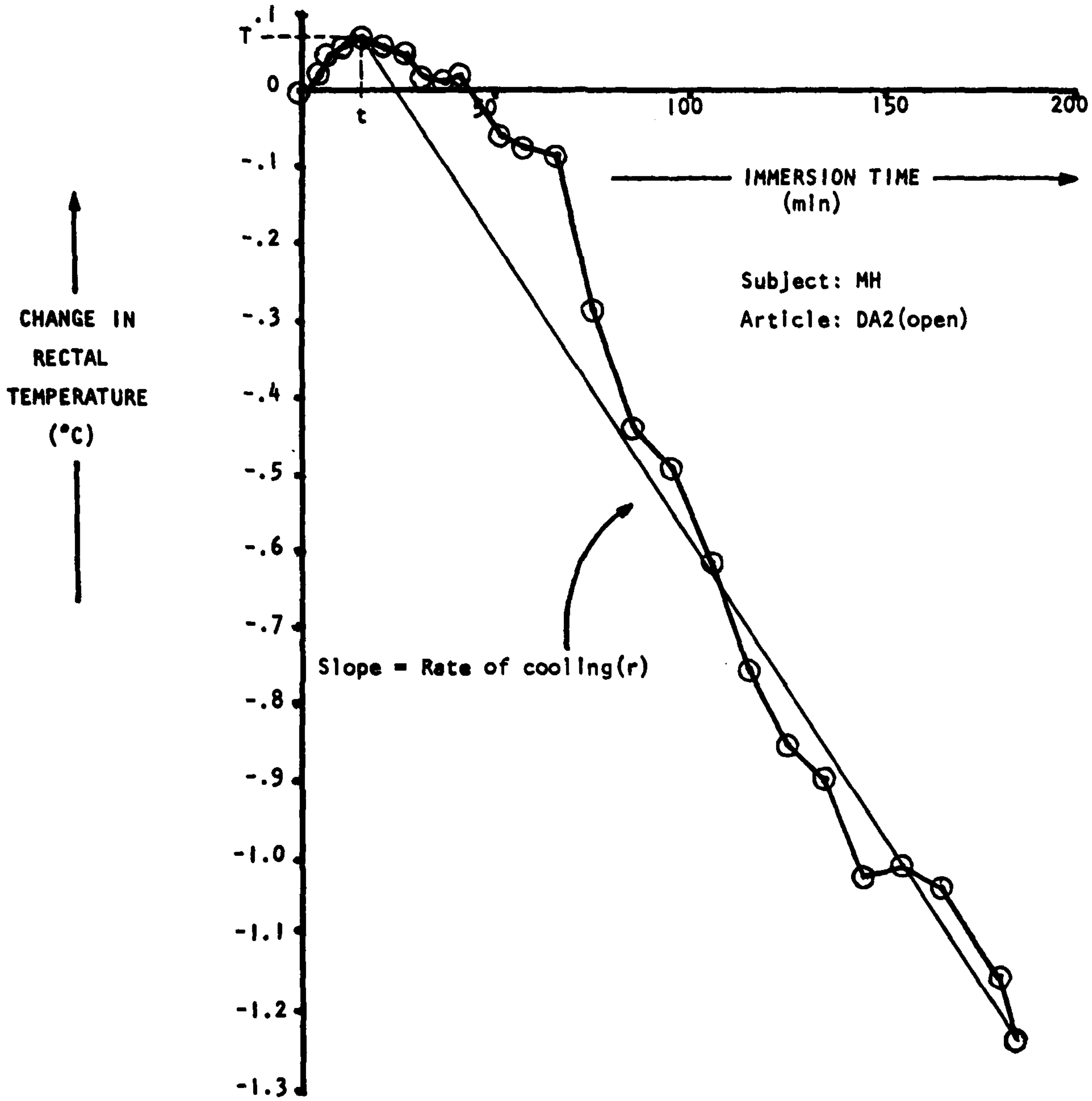


TABLE I-7
RESULTS OF COLD-IMMERSION EXPERIMENTS

Test Article	Parameters						
	t (hrs)		T (°C)		r (°C/hr)		
	Mean	S.E.M.	Mean	S.E.M.	Mean	S.E.M.	S. D.
WE1*	.37	.16	.11	.02	0.64	.16	.36
WE2	.34	.09	.25	.09	0.62	.13	.29
WE3*	.33	.11	.15	.04	0.46	.10	.23
WP1*	.25	.07	.18	.09	1.06	.34	.76
WP2*	.36	.04	.15	.05	0.51	.05	.11
WP3*	.32	.07	.20	.08	1.09	.46	1.03
WP5*	.31	.06	.29	.05	1.19	.46	1.13
WP6*	.33	.05	.14	.03	0.48	.12	.27
WP7*	.19	.08	.20	.08	1.68	.49	1.20
D2 *	.59	.15	.30	.13	0.55	.10	.25
D3 *	.40	.02	.26	.09	1.30	.40	.89
DF1 (PVC)	.22	.09	.04	.02	0.37	.03	.07
DF2	.36	.07	.12	.03	0.48	.10	.25
DF3	.45	.10	.15	.03	0.47	.07	.16
DA1	.54	.11	.13	.03	0.33	.03	.07
DA2 (closed)	.16	.08	.04	.02	0.27	.03	.07
DA2 (open)	.42	.12	.06	.03	0.44	.01	.02

* Results obtained in approximately 11.8°C water, other results obtained in approximately 1.7°C water.

contribute more than a small proportion of reasonable survival times (a few hours or more depending upon the suit).

3.4 Analysis and Discussion

[illegible] of the cold-immersion experiments, the first step was to develop [illegible] to predict, for each test article, the parameters of the cooling model for the body structures of interest (thin, average and heavy). Because the parameters t and T were expected to have relatively little impact upon survival-times estimates, it was decided that this effort would be concentrated upon predicting the rate of cooling r and that the survival-time estimates for each suit would be based upon the average values $\bar{t}$ and $\bar{T}$ shown in Table 1-7.

Development of Cooling-Rate Regression Predictors

A set of six quantitative measures of physical/metabolic attributes were composed and investigated to determine if one would explain the variation in cooling rates observed with each of the test articles. The indices, denoted X1 through X6 are defined as follows.

$$1.\quad X1 = \left[\frac{\text{Heath-Carter III}}{(\text{Heath-Carter I})\cdot(\text{Heath-Carter II})}\right]$$

$$2.\quad X2 = \left[\frac{X1}{\text{Metabolic Rate After 1-Hour Immersion}}\right]$$

$$3.\quad X3 = \left[\frac{\text{Weight}}{\text{Surface Area}}\right]$$

$$4.\quad X4 = \left[\frac{\text{Mean Reciprocal Skinfold Thickness}}{X3}\right]$$

$$5.\quad X5 = \left[\frac{(\text{Surface Area})\cdot(\text{Mean Reciprocal Skinfold Thickness})}{\text{Metabolic Rate After 1-Hour Immersion}}\right]$$

$$6.\quad X6 = \left[\text{Total Skinfold Thickness}\right]^{-1}$$

The first index, X1, is based entirely on the three components of the Heath-Carter somatotype method. This index was found by Hayward, et al., (1978) to explain cooling-rate variation moderately well. The second index, X2, was formulated to determine what improvement in the performance of X1 would result from including the consideration of the individual's capabilities to generate heat. Metabolic rate measured after 1 hour in the cold was chosen since it was available most consistently. The third index, X3, is formulated to consider the individual's propensities to exhibit thermal inertia as measured by body weight and the area that he possesses through which heat may be lost. The fourth index, X4, was recommended by Keatinge (1979) as

having worked well in his experience. The "mean reciprocal skinfold thickness" was computed as $(\sum_{i=1}^{3} S_i^{-1})/3$ where S_1, S_2 and S_3 are the tricep, subscapular and suprailiac skinfold thicknesses. The fifth index, X5, was formulated to consider the primary thermodynamic factors which should affect changes in core temperature -- surface area, thermal conductivity of surface material and the rate of internal heat production. The last index, X6, was formulated to be a simple measure of fatness. Of the 6 indices, X1, X2, X4, X5 and X6 were arranged to be direct indicators of expected cooling rate. That is, cooling rate would be expected to increase as each of them increase. Index X3 is arranged in reverse fashion -- cooling rate should decrease as X3 increases.

Each of these indices were computed for each test subject from the data presented in Table I-5. First-order, least-squares regression relations were established relating cooling rate to each of the 6 indices for each test article. They are of form $r' = ax + b$ where the x is one of the 6 indices and r' is the predicted cooling rate. The accuracy with which regression relations conform to data is often expressed by "F test statistics". The significance of these statistics may be interpreted by the "level of significance" at which the hypothesis, that the observations follow the linear model ($r' = ax + b$), may be rejected. Small levels of significance indicate that the regressions conform well to the observations. Table I-8 presents the significance levels for the $r' = ax + b$ regressions for each index and each test article. No regressions were possible with indices X2 and X5 for test article DA2 since metabolic rate data during immersion was unavailable. Table I-8 also shows the average and maximum of the significance levels for each index. The best indices are X4 and X6 which exhibit an average significance level of about 2 percent and a maximum significance level less than 7 percent. This indicates that either of these indices could be used to predict cooling rates for this collection of test articles. Because of its simplicity index X6 was chosen for use in this study.

Index X6 has a value of 1/30.6 = 0.0327 for the average of the test subjects participating in this study. This corresponds to a value of 3 in component I of the Heath-Carter somatotype method. The "middle range" for this component is from 3 to 5 (Carter, 1975). This indicates that the group of test subjects described in Table I-5 (all college students) are thinner than a comparable group selected at random from the population at large.

TABLE I-8

SIGNIFICANCE OF INDICES FOR PREDICTING COOLING RATES

($r' = ax + b$ Model)

Test Article	Physical/Metabolic Attribute Indices					
	X1	X2	X3	X4	X5	X6
WE1	.080	.084	.087	.060	.078	.065
WE2	.050	.048	.031	.031	.034	.032
WE3	.066	.064	.064	.064	.054	.066
WP1	.044	.019	.082	.012	.131	.006
WP2	.003	.004	.001	.002	.004	.002
WP3	.158	.213	.119	.068	.165	.067
WP5	.001	.001	.026	.007	.005	.006
WP6	.006	.002	.022	.024	.064	.026
WP7	.009	.005	.005	.003	.090	.002
D2	.013	.008	.004	.006	.002	.006
D3	.133	.132	.130	.046	.101	.053
DF1 (PVC)	.004	.002	.003	.002	.001	.002
DF2	.006	.002	.016	.011	.007	.011
DF3	.008	.009	.010	.006	.011	.008
DA1	.006	.006	.007	.005	.003	.004
DA2 (closed)	.003	-	.001	.007	-	.007
DA2 (open)	.000	-	.000	.000	-	.000
Average	.035	.040	.036	.021	.050	.021
Maximum	.158	.213	.130	.068	.165	.067

Elements in table are levels of significance at which the regressions may be accepted as accurate predictors of cooling rate.

However, these test subjects may be more representative of military personnel, merchant seamen and recreational boaters who may be more fit than the population at large. To establish a quantitative description of the "thin" and "heavy" individuals for survival-time estimation, Heath-Carter component I values of 2 and 6 will be used. These values correspond to 21 and 62 mm total skinfold thicknesses, respectively. Reviewing the data describing the range of total skinfold thickness with which each suit was tested (Table I-6), it may be seen that all test articles were tested at or near a 21 mm total skinfold thickness but none were tested near 62 mm. This means that the regression relations for predicting cooling rates are valid for thin (21 mm) and average (30.6 mm) individuals but are not necessarily valid for heavy (62 mm) individuals. Therefore another model must be developed in which more confidence can be placed for predicting cooling rates of heavy individuals.

As skinfold thickness increases its reciprocal (index X6) decreases approaching zero and presumably the corresponding cooling rate decreases toward zero. A zero value of the reciprocal of total skinfold thickness, which means infinite total skinfold thickness, is of no practical importance. However, by forcing a linear cooling-rate predictor to indicate a cooling rate of zero when the reciprocal of total skinfold thickness reaches zero and by simultaneously forcing it to give the best (least-squares) fit to the experimental data, one may achieve reasonable extrapolations of the cooling-rate observations for large skinfold thicknesses (small reciprocals).

The linear model which passes through the origin is of form $r' = c \cdot x$. The least squares estimator for the coefficient c for a particular test article is:

$$c = \left[\frac{\sum_{i=1}^{n} X_i \; r_i}{\sum_{i=1}^{n} X_i^2} \right]$$

where n = the number of cold-immersion experiments with the test article

X_i = index value for subject in experiment i with the article.

r_i = cooling rate observed in experiment i with the article.

These linear models were developed for each of the test articles and evaluated (as the $r' = a \cdot x + b$ models were) with the F test statistics. The levels of significance of the models using index X6 were calculated for each test article. The average of them is about 0.6 percent and the maximum is about 2.4 percent. This indicates that these models using index X6 are quite accurate. Hence,

they will be used to estimate the cooling rates for heavy individuals. The cooling-rate, regression predictors for thin, average and heavy individuals are shown for each test article in Table I-9. Both regression models are based on analysis of the exact values of index X6 and the cooling rates observed with each subject testing each article. The numbers of data points analyzed for the test articles are indicated in Table I-4 by "Number of Replications".

It is interesting to note that the only two appearances of negative values of "a" (the coefficient of the first order term in the basic cooling-rate, regression predictor) occurred for the two sets of experiments conducted with test article DA2. It was previously indicated that the X6 index varies directly with anticipated cooling rate. The negative coefficients of the index in the DA2 models reverses this behavior. This indicates that thin individuals cool slower than heavier ones in that suit (a reversal of the normal relationship). It should be recalled that DA2 is a one-size-fits-all inflatable suit. The reversal might result from thin individuals allowing the suit to inflate to a greater thickness than is possible with a larger person wearing the suit. This would provide greater buoyancy and thermal protection for a thinner individual. The increased buoyancy and lighter weight of the thinner individual would reduce the surface area immersed in the cold water. While this result was not found with the other inflatable test article (DA1), a relatively small value of "a" was found. The failure of the sign to reverse could indicate that, while generally the same factors described for DA2 were acting, the separate outer shell of DA1, which preserves more uniform effective air spacing between wearer and water, renders it less sensitive to those factors.

Establishing Cooling-Rate and Survival-Time Estimates

To determine the cooling rate estimates for individuals with the three selected total skinfold thicknesses one simply has to evaluate the appropriate predictor model, given in Table I-9, at the appropriate value of the X6 index (thin 0.0476; average 0.0327; and heavy 0.0161). The resulting cooling rate predictions are given in Table I-10. These rates are those expected when individuals with the various somatotypes are immersed in water of the temperatures in which the various suits were tested. The negative first-order coefficients discussed earlier for test article DA2 have resulted in larger cooling rates for average individuals

TABLE I-9

COOLING-RATE † PREDICTOR MODELS

Test Article	"Thin And Average" Individuals ($r' = ax + b$ Models) a	b	"Heavy" Individuals ($r' = cx$ Models) c
WE1*	20.514	-0.125	17.262
WE2	29.838	-0.319	19.990
WE3*	0.987	0.427	13.435
WP1*	74.746	-1.535	33.097
WP2*	11.147	0.124	14.558
WP3*	77.702	-1.527	35.391
WP5*	116.224	-2.580	41.372
WP6*	31.062	-0.456	16.546
WP7*	132.123	-2.858	52.963
D2*	20.570	-0.203	15.201
D3*	76.328	-1.705	34.505
DF1 (PVC)	7.038	0.119	10.219
DF2	16.076	-0.138	12.649
DF3	22.673	-0.378	12.775
DA1	3.570	0.202	8.496
DA2 (closed)	-1.956	0.346	6.484
DA2 (open)	-0.271	0.451	10.738

† Cooling rates given in °C/hr

* Cooling rates predicted for immersion in 11.8°C water, other cooling rates predicted for immersion in 1.7°C water.

TABLE I-10

COOLING RATE † ESTIMATES
(Experiment Water Temperatures)

Test Article	Morphology					
	Thin		Average		Heavy	
	Estimate	S.D.	Estimate	S.D.	Estimate	S.D.
WE1*	0.852	.484	0.546	.424	.278	.588
WE2	1.101	.486	0.657	.305	.322	.420
WE3*	0.474	.588	0.459	.407	.216	.424
WP1*	2.023	.388	0.909	.333	.533	.715
WP2*	0.655	.099	0.489	.083	.234	.109
WP3*	2.172	.963	1.014	.816	.570	1.092
WP5*	2.952	.851	1.221	.579	.666	1.285
WP6*	1.023	.355	0.560	.229	.266	.313
WP7*	3.431	.641	1.462	.540	.853	1.186
D2*	0.776	.261	0.470	.229	.245	.311
D3*	1.928	.892	0.791	.867	.556	.416
DF1(PVC)	0.454	.085	0.349	.071	.165	.103
DF2	0.627	.280	0.388	.247	.204	.406
DF3	0.701	.181	0.363	.149	.206	.274
DA1	0.372	.084	0.319	.079	.137	.124
DA2(closed)	0.253	.079	0.282	.075	.104	.175
DA2(open)	0.438	.044	0.442	.042	.173	.207

† Cooling rates given in °C/hr

* Cooling rates predicted for immersion is 11.8°C water, other cooling rates predicted for immersion in 1.7°C water.

than for smaller individuals. This, of course, assumes that these individuals (thin and average) are immersed in the same type of one-size-fits-all suit. Custom fitting or even simple sizing could change this. It should be noted that the use of the $r' = cx$ model to predict cooling rates for heavy individuals wearing DA2 implicitly assumes that sizing to fit will be done.

Table 1-10 also shows the standard deviations (S.D.) of each of the cooling rate predictions obtained from the regression relations. These standard deviations were computed for each test article and body morphology as follows.

$$S.D. = \left\{ MSE \cdot \left[1 + \frac{1}{n} + \frac{(X^P - \bar{X})^2}{\sum_{j=1}^{n} (X_j - \bar{X})^2} \right] \right\}^{1/2}$$

where MSE = mean square error from analysis of variance performed on the respective regression relationship

n = number of subjects testing the article

X^P = value of (total skinfold thickness)$^{-1}$ for which cooling rate is to be predicted

X_j = value of (total skinfold thickness)$^{-1}$ for subject j testing the article (j = 1, 2,....., n)

$\bar{X} = (\sum_{j=1}^{n} X_j)/n$

These standard deviations recognize the intrinsic error in the regression relation, the size of the sample upon which it is based as well as the proximity of the value of the independent variable, at which the prediction is developed, to the values upon which the regression is based. These standard deviations indicate clearly that the cooling rate predictions involve less error for the average body morphology than for the thin or heavy ones.

Comparing the standard deviations for the average man to those for the cooling rates in Table 1-7, it may be seen that the regression-based approach to estimating cooling rates which are sensitive to somatotype variation has produced only small reductions in random variation. Thus the main contribution of the regression-based analysis has been that it allowed survival-time estimates to be developed for selected somatotypes for all test articles.

core temperature stabilization such as seen for this subject and others

This gives comparability in the results even though different groups of subjects tested each article. It is important to notice that though random variation was n ot reduced as much as had been hoped, it was certainly not increased to any significant extent by the analysis approach. It was increased for only three test articles: WE1, WE3 and DA2 (open); and these increases are unimportant in the comparison of the test articles because of the close agreement between the sample means ($\bar{r}$) and the regression estimates (r') for these three articles. The survival time estimates for thin and heavy individuals (though their random variation may be seen to be often large) could not have been developed without the regression-based analysis.

Each survival time is formulated as the time required for the individual to cool to 30°C core temperature. This time is the sum of that required for temperature to reach its peak value plus the time required for subsequent cooling to 30°C. It will be assumed that the time required to reach the peak temperature is the mean of these times ($\bar{t}$) observed with the respective test articles. It will also be assumed that the individual enters the water with a "normal" core temperature of 37.56°C and that his initial increase in core temperature will be the same as the mean of these values ($\bar{T}$) observed with the respective test articles. Thus cooling begins from a peak temperature of $(37.56 + \bar{T})$°C. The survival-time estimate (S) is as follows

$$S = \bar{t} + \frac{(37.56 + \bar{T}) - 30}{r'}$$

where $\bar{t}$ and $\bar{T}$ are selected for the appropriate test article from Table I-7 and r' is selected for the appropriate test article and morphology from Table I-10. The survival-time estimates resulting from this calculation are shown in Table I-11 ranked in order of decreasing values for the average individual. The test articles have been divided into two groups in this table. Those listed above the horizontal line were tested in 1.7°C(35°F) water. Those listed below the line were tested in 11.8°C(53.2°F) water. To achieve comparability among these two groups of test articles, the survival-time estimates for those tested in 11.8°C water will be adjusted (shortened) to approximate those which would result when immersed in 1.7°C water. It should

<u>Observations on the Nature of Core Cooling</u>

TABLE I-11

SURVIVAL-TIME † ESTIMATES
(Experiment Water Temperatures)

Test Article	Morphology Thin	Average	Heavy
DA2 (closed)	30.2	27.1	73.2
DA1	21.2	24.6	56.7
DF1 (PVC)	17.0	22.0	46.3
DF3	11.4	21.7	37.9
DF2	12.6	20.2	38.0
DA2 (open)	17.8	17.7	44.5
WE2	7.4	12.2	24.6
D2*	10.7	17.3	32.7
WE3*	16.6	17.1	36.0
WP2*	12.1	16.1	33.3
WE1*	9.4	14.4	28.0
WP6*	7.9	14.1	29.3
D3*	4.5	10.3	14.5
WP1*	4.1	8.8	14.8
WP3*	3.9	8.0	13.9
WP5*	3.0	6.7	12.1
WP7*	2.5	5.5	9.3

† Survival time estimates given in hours.

* The estimates for these test articles apply for immersion in 11.8°C water.

be noted that in Table I-II only the lowest-ranked test article of the top group would rank below any of those in the bottom group if the groups were merged.

The problem of adjusting the survival-time estimates for changes in immersion-water temperature is a complex but unavoidable one. It is unavoidable if one wants to identify the least-inhibiting suit that will give at least 4 hours of survival time in 1.7°C water. The problem is complicated because much more than mere thermodynamics is involved. When immersion-water temperature is lowered by 10.1°C one can expect a more pronounced elevation in rates of thermogenesis and possibly more pronounced peripheral vasoconstriction as well. These differences in physiologic responses may, to some degree, offset the increased rate of heat loss to be expected because of the increase temperature gradient existing between the immersion victim and the water. However, these response differences may be expected to vary among the test articles due to variation in the rates of cooling of different body surface areas.

The best available approach for quantitatively predicting the impacts, upon the cooling process, of immersion in colder water while wearing the suits which were tested in 11.8°C water, is to perform a detailed numerical simulation of the immersion, including consideration of characteristics of the test articles. Part III of this report addresses an investigation of the accuracy of a variety of mathematical models for performing simulation of cold immersion. It is concluded in Part III that even with the best model considered (Montgomery's model) and with an improved metabolic rate control submodel substituted, the accuracy with which the model represents actual observations varies among the test articles. Therefore, one may not assume that the model produces results which are comparable among the test articles in colder water.

However, it is possible to use model simulation results to modify observations obtained in 11.8°C water to produce estimates for 1.7°C water without assuming that the model is accurate in an absolute sense. Instead one must assume only that the model's results, obtained for a given test article in different water temperatures, are relatively accurate (changes are proportionally accurate). This weaker assumption enables the estimation

4.0 MOBILITY-REDUCTION INVESTIGATION

of proportional changes in the parameters of the cooling models ($\bar{t}$, $\bar{T}$, r') due to changes in immersion-water temperature, which may then be used to adjust the corresponding parameters developed from the data obtained from experiments in 11.8°C water. From these adjusted parameters, corresponding survival-time estimates can be developed. This process is symbolically described in the following algorithm.

1. Define parameters based on results in 11.8°C water.

   $\bar{t}_i$ = mean time for temperature to peak in test article i (i = 1, 2, ..., 10, since 10 suits were tested in 11.8°C water)

   $\bar{T}_i$ = mean elevation in rectal temperature at peak value in test article i

   r'_{ij} = regression-predicted cooling rate for morphology j in test article i (j = 1 represents thin, 2 represents average, 3 represents heavy

2. Define morphologies in terms of model inputs.

Morphology	Ht (cm)	Wt (kg)	Body Fat (%)*
thin	182.9	65.5	3.2
average	180.4	73.4	9.6
heavy	182.9	86.4	15.3

   *Based on estimation in Montgomery's model drawn from Siri (1956)

3. Perform mathematical simulation for each morphology in each test article in 11.8°C and 1.7°C water. Determine

   f_i = ratio of time for temperature to peak for average morphology and test article i in 1.7°C water to the corresponding elevation in 11.8°C water

   g_i = ratio of elevation in rectal temperature at peak value for average morphology and test article i in 1.7°C water to the corresponding elevation in 11.8°C water

   h_{ij} = ratio of rate of cooling (peak to end) for test article i and morphology j in 1.7°C water to the corresponding rate of cooling in 11.8°C water

TABLE I-15
ELEMENTARY MOVEMENTS CONSIDERED AND SELECTED

4. Estimate time for temperature to peak in test article i in 1.7°C water (K_i).

$$K_i = f_i \cdot \bar{t}_i \text{ for } i = 1, 2, \ldots\ldots, 10$$

5. Estimate elevation in rectal temperature at peak value in test article i in 1.7°C water (L_i)

$$L_i = g_i \cdot \bar{T}_i \text{ for } i = 1, 2, \ldots\ldots, 10$$

6. Estimate cooling rate for morphology j in test article i in 1.7°C water (M_{ij})

$$M_{ij} = h_{ij} \cdot r'_{ij} \text{ for } i = 1, 2, \ldots\ldots, 10 \text{ and } j = 1, 2, 3.$$

7. Construct survival-time estimates for test article i and morphology j in 1.7°C water (S'_{ij}).

$$S'_{ij} = K_i + \frac{(37.56 + L_i) - 30}{M_{ij}}$$

This approach to adjusting the cooling model parameters is consistent with the earlier development of parameters based on experimental observations in that distinctions in values of the minor parameters (t and T or K and L), due to variation in body structures, are not made.

The parameter ratios (f_i, g_i and h_{ij}) obtained by exercising Montgomery's model including the improved metabolic-rate-control submodel, 1.7°C-water results in the numerator and 11.8°C-water results in the denominator, are shown in Table I-12. The mathematical model could not simulate the effects of a device covering only part of the torso. Therefore, no results and hence no ratios could reasonably be obtained for WP7. For purposes of adjusting cooling parameters to allow estimation of survival time in 1.7°C water, it was assumed that the parameter ratios for WP7 are the same as those for WP5. It should be noted that the ratios of times to reach peak temperatures range from 1/3 to 3/4. The ratios of elevations in temperatures are based on small numbers, hence their range is relatively large (0 to 5). The ratios of cooling rates are generally well behaved among the test articles and among the body structures.

The cooling parameters resulting with the use of these adjustment factors are shown in Table I-13. These adjusted parameters are identified

FIGURE I-6
SELECTED ELEMENTARY MOVEMENTS

TABLE I-12

RATIOS † OF COOLING PARAMETERS FROM MATHEMATICAL MODEL

Test Article (i)	Ratios of Times to Peak Temperatures (f_i)	Ratios of Elevations in Temperatures (g_i)	Ratios of Cooling Rates (h_{ij}) Thin	Average	Heavy
WE1	.500	5.000	1.884	1.969	2.250
WE3	.667	4.000	1.864	2.007	2.118
WP1	.667	1.000	1.863	1.987	2.092
WP2	.500	0	1.700	1.769	1.841
WP3	.500	1.500	1.923	1.958	2.240
WP5	.750	1.500	1.987	2.040	2.366
WP6	.600	1.250	2.009	2.050	2.446
WP7*	.750	1.500	1.987	2.040	2.366
D2	.333	2.000	1.793	1.816	2.023
D3	.500	1.500	1.683	1.750	1.912

† Ratios constructed with 1.7°C-water parameters divided by 11.8°C-water parameters.

* Ratios for WP7 assumed same as for WP5

FIGURE I-6 (CONTINUED)
SELECTED ELEMENTARY MOVEMENTS

TABLE I-13
COOLING PARAMETERS ESTIMATED FOR 1.7°C WATER

Test Article (I)	Times to Peak Temperatures (K$_I$)	Elevations in Temperatures (L$_I$)	Cooling Rates (M$_{IJ}$)		
			Thin	Average	Heavy
WE1	.19	.55	1.605	1.075	0.623
WE3	.22	.60	0.884	0.921	0.457
WP1	.17	.18	3.769	1.806	1.115
WP2	.18	0	1.114	0.865	0.431
WP3	.16	.30	4.177	2.013	1.277
WP5	.23	.44	5.866	2.491	1.576
WP6	.20	.18	2.055	1.148	0.651
WP7	.14	.30	6.817	3.000	2.018
D2	.20	.60	1.391	0.854	0.500
D3	.20	.39	3.245	1.384	1.063

is a composite showing the elementary movements which were selected for inclusion in the study. Selections were based upon importance of the

by the symbols used to represent them in the algorithm stated earlier. The survival time estimates produced by the last step of the algorithm for those articles tested in 11.8°C water are shown in Table I-14. To facilitate comparisons among the 1.7°C-water, survival times for all the test articles, the results for articles tested in 1.7°C water have been repeated in Table I-14. The estimated survival times for average men are presented graphically in Figure I-3.

Discussion

A number of interesting observations may be drawn from the results in Table I-14. The respiratory heat reclamation feature of DA2 seems to significantly extend survival time. That for the average individual is extended from 17.7 to 27.1 hours. It should be noted that "dry foam" and "dry air" suits were categorically superior to dry suits and wet suits. This is consistent with the results of Hayward, et al. (1978). Suit D3 was regularly observed to contain significant amounts of water following cold-immersion experiments. It, therefore, should not be regarded as a proper dry suit. The other dry suit (D2) did not suffer this difficulty and performed better than all but one of the wet suits for an average individual. The best wet suit was WE2, probably due to its snug fit and resistance to flushing. The best wet-mode, partial-body suit, WP2, was the only one indicated to provide a thin individual more than four hours of survival time. The next-best suit, WP6, is indicated to provide a thin individual about four hours of survival time. The longer survival times for the thin individual than for the average one in suit DA2 (open and closed) are due to the regression predictors obtained for that suit and probably result from the factors discussed earlier.

3.5 Special Observations

Detailed Metabolic Rate Observations

During the course of this investigation, an instrument became available for a short period of time by which the rate of oxygen consumption of a subject could be monitored continuously during an experiment. The device is

TABLE I-14

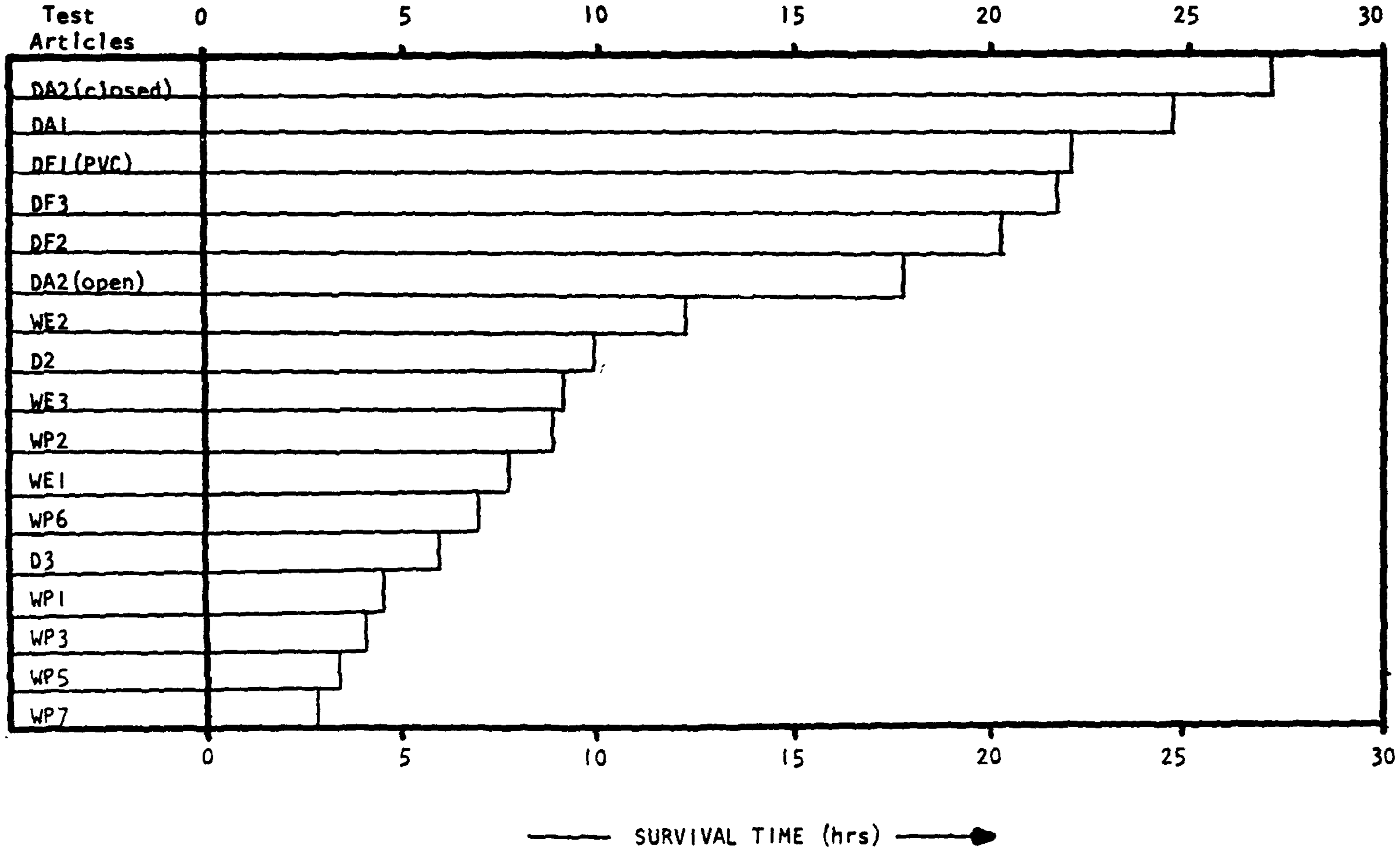
SURVIVAL TIME † ESTIMATES IN 1.7°C WATER

Test Article	Morphology		
	Thin	Average	Heavy
DA2 (closed)	30.2	27.1	73.2
DA1	21.2	24.6	56.7
DF1 (PVC)	17.0	22.0	46.3
DF3	11.4	21.7	37.9
DF2	12.6	20.2	38.0
DA2 (open)	17.8	17.7	44.5
WE2	7.4	12.2	24.6
D2*	6.1	9.8	16.5
WE3*	9.5	9.1	18.1
WP2*	7.0	8.9	17.7
WE1*	5.2	7.7	13.2
WP6*	4.0	6.9	12.1
D3*	2.6	5.9	7.7
WP1*	2.2	4.5	7.1
WP3*	2.0	4.1	6.3
WP5*	1.6	3.4	5.3
WP7*	1.3	2.8	4.0

† Survival-time estimates given in hours.

* Survival time estimates based on adjustments to cooling parameters observed in 11.8°C water.

FIGURE I-3
ESTIMATED SURVIVAL TIMES FOR AVERAGE MEN
(1.7°C WATER)



the MRM-I Oxygen Consumption Computer manufactured by Waters Instrument, Inc. It was used to determine the metabolic rates for subjects BS and GE (both of whom were wearing test article D3 in 11.8°C water) in a quasi-continuous fashion. The device repeatedly averaged the rate of oxygen consumption over consecutive minute periods and recorded these average rates. Because of a known bias in the instrument when measuring low rates of oxygen uptake (below 0.5 l/min) a linear correction, supplied by the manufacturer, was applied to all such low rate measurements recorded. This correction is as follows.

$$\text{Adjusted rate} = 0.7539\ (\text{recorded rate}) + 0.1280$$

The conversion of oxygen uptake rates to metabolic rates (in kcal/hr) was done by the standard technique employed when measuring metabolic rate with a spirometer. That is, by assuming that an oxygen consumption of 1 liter (STP) is equivalent to 4.82 kcal.

The metabolic rate data for subject BS and GE are shown in Figure I-4 and Figure I-5 respectively. They show rapid fluctuation of the metabolic rate around an easily discernable average metabolic rate which is changing more slowly. Both changes are of interest in the thermo regulatory process.

The changes in rectal temperature for these experiments are shown on page B-11 of Appendix B. For both subjects the average metabolic rate and the rectal temperature changes track very well. The rectal temperature of subject GE remains unchanged for approximately 35 minutes and then starts dropping rapidly. His average metabolic rate follows a similar time course except that as the rectal temperature falls, the average metabolic rate increases rapidly until at approximately 75 minutes it levels off at a rate which may be the maximum obtainable through shivering.

The time course of the rectal temperature and average metabolic rate of subject BS also follow very closely with an increase in metabolic rate corresponding to a decrease in rectal temperature. The stabilization of his rectal temperature after approximately 125 minutes is interesting in that there is also a stabilization of the metabolic rate from approximately 140 to 170 minutes. The dip in metabolic rate at about 170 minutes is not fully understood. It may result from the reaction of the body's metabolic rate control mechanism to the stabilization of core temperature. The possible effects of

FIGURE 1-4
METABOLIC RATE RESPONSE :
SUBJECT BS

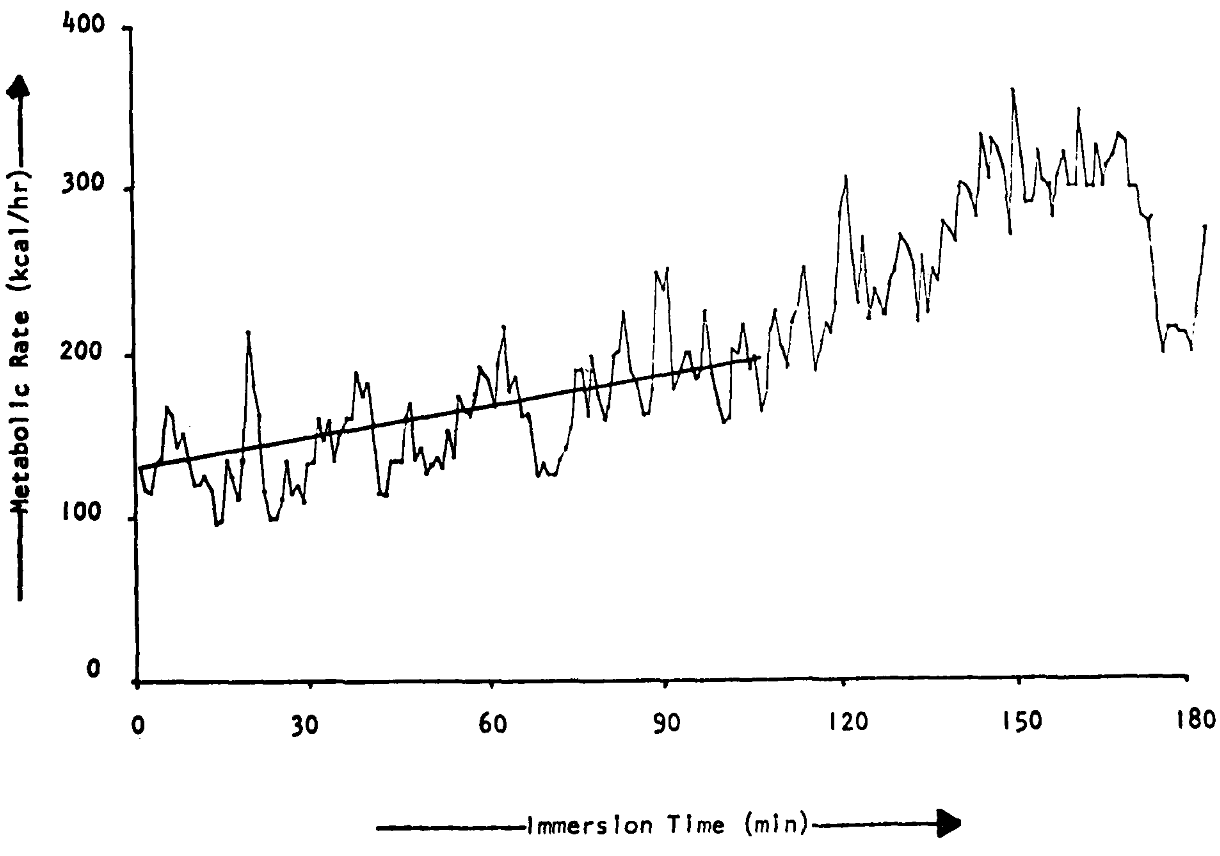
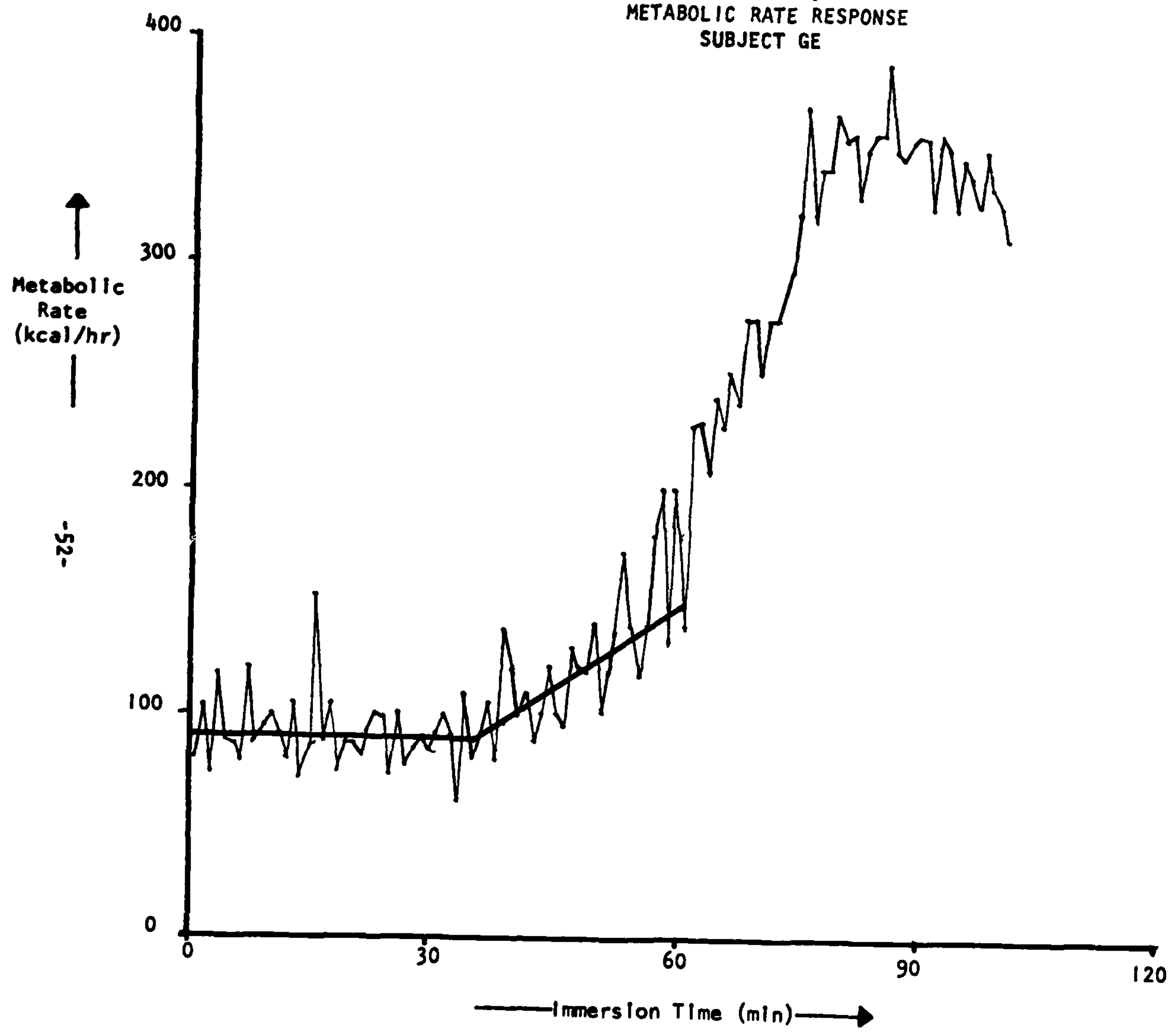


FIGURE I-5
METABOLIC RATE RESPONSE
SUBJECT GE



core temperature stabilization such as seen for this subject and others are discussed later in this section.

The short-term variations of the metabolic rate observations for these two subjects were quantitatively analyzed for periodic components. Because of the seemingly random nature of the variations, it is difficult to detect these components if they are present throughout the time course of the responses. The method used for detecting periodicities in these responses is to correlate the response with itself by computing its autocorrelation function. Before this was done, the large average values of the two responses were removed so that any periodicities in the autocorrelation function would not be obscured. This was done by subtracting the values indicated by the bold lines shown in Figures I-4 and I-5, from the response. Only the first 110 minutes of the response of subject BS were analyzed and the first 60 minutes for subject GE. The autocorrelation functions were obtained by computing the inverse Fourier transforms of the power spectral density functions of the responses. Both of these transforms were obtained using a fast Fourier transform algorithm described by Bergland (1969).

The autocorrelation function for the response of subject GE showed a periodicity in the response having a period of 2 minutes. This corresponds to a frequency of twice the sampling frequency and may not be of physiological significance. However, the autocorrelation function for subject BS showed a periodic component with a period of 8 minutes was strongly present in his metabolic rate response. This means that in each 8 minute period of the metabolic rate data, there is a maximum rate of oxygen uptake and a corresponding minimum rate of oxygen uptake. In many of the experiments it was observed that the subjects exhibited a cyclic shivering pattern. It is most probable that the cyclic variation of the metabolic rate in the case of subject BS was due to this cyclic shivering.

It must be emphasized that the two sets of metabolic rate data reported here are not sufficient to establish the behavior of the thermoregulatory process. However, the results are intriguing and suggestive of further research.

Observations on the Nature of Core Cooling

In Section 3.3 three considerations were presented which are thought to be relevant to the selection of a model to represent the cooling process. One of them was the correspondence or fit between experimental observations and the model over the range of the observations. This consideration was judged to be of less significance than the others for the purpose (extrapolation) to be served by the model in this study. It is appropriate, before concluding discussion of this investigation, to reflect on certain of the responses shown in Appendix B which are particularly interesting and potentially significant to modeling of the cooling process.

It was earlier argued that a reasonable expectation exists that, after some cooling, a well-protected individual might be able, through accelerated thermogenesis, to resist further reductions in core temperature. By achieving and maintaining thermal equilibrium, significant extensions of surival would be possible. The occurrence of this thermal equilibrium would, of course, be strongly dependent upon the temperature of the water and the efficiency of the protection device. One would also expect that somatotypic factors would also play a role in affecting the onset of thermal equilibrium.

The occurrence of thermal equilibrium would be associated with a more or less stabilized core temperature. Because of the cyclic nature of shivering thermogenesis, some variations in core temperature might be anticipated. However, the definition of thermal equilibrium implies that the larger, downward drift in core temperature would be arrested. This general response may be seen for the following test articles and test subjects in the data in Appendix B.

Test Articles	Test Subject(s)
WE1	JH, SW
WE2	PK
WE3	SW, BH, GF
WP1	RM
WP2	KC
WP3	BH, PK
WP6	MO, BH, PK
WP7	JC
D2	GE
D3	BS
DF2	BS, TP, MK
DF3	MO, MK, SW
DA1	MH
DA2 (closed)	JR, MH

The apparent "rebounds" in the core temperature responses are not unlike responses reported by the Royal Australian Air Force (1977).

The problem in interpreting these stabilizations of core temperature is the irregularity of their occurrence. They occurred over the whole range of body structures represented by the test subjects. Yet they sometimes did not occur when one would have thought they should, for example, with test article DFI (PVC).

Equally distrubing is the notion that, if immersion experiments had been terminated somewhat earlier, then relatively short-lived phenomena might be misinterpreted as a sustainable thermal equilibrium. This might have happened with the following experiments.

Test Articles	Test Subjects
WEI	GF, MK
D2	CM
D3	RM
DAI	RM

Stabilizations of core temperature during cold immersion have occurred and are potentially significant to the estimation of survival times. The question remains, would the stabilizations have been maintained as long as metabolic substrate was available to support the elevated metabolic rate or are they transient phenomena which would not persist to materially effect survival. Uncertainty over this question as well as the inability to predict reliably the occurrence of the stabilizations have prompted the decision not to include stabilizations in the survival time estimation process. Of course, when stabilizations did occur during cold-immersion experiments they effectively reduced the cooling rate parameters estimated for those experiments. However, these stabilizations remain protentially significant and warrant further study to develop an understanding of their real implications to survival.

4.0 MOBILITY-REDUCTION INVESTIGATION

One of the central components of the decision to select an article of cold-protection equipment for use in a constant-wear mode is its interference with the wearer's ability to move in the performance of his job. It would normally be the performance of this job which motivated the exposure to the risk of accidental cold-water immersion in the first place.

4.1 Objectives

The objective of the mobility-reduction investigation was to quantitatively assess the interference with mobility associated with wearing each test article selected for this investigation (see Table 1-2). These articles are potentially useful to individuals involved in a variety of jobs. The specific kinds of mobility (e.g., leg mobility versus arm mobility) which are important vary among jobs. It was desired that this investigation provide results which are not only useful for a particular job but which could be used to determine the suitability of each article for a variety of potential uses. It was also desired that this investigation provide results which are not only useful for individuals with particular types of body structure but which would be valid for a broad range of body structures.

4.2 Methodology

The first step in the mobility-reduction investigation was the selection of elementary movements of the body from which overall mobility is constituted. To achieve results applicable to the broadest possible range of individuals wearing the devices, the general approach employed in goniometry (the measurement of joint motion) was used (see Cave and Roberts, 1936, and Cole, 1971). The elementary movements considered were all angular deflections of joints. These movements, unlike stepping, reaching and others, are essentially independent of the individuals height and weight over reasonably broad ranges of these two parameters. The movements which were considered and selected for inclusion in the study are indicated in Table 1-15. Movements which are simply returns to starting positions, such as shoulder adduction, elbow, knee and metacarpophalangeal extensions, and spine and cervical lateral extensions, were not considered and are not listed in Table 1-15. Figure 1-6

TABLE I-15
ELEMENTARY MOVEMENTS CONSIDERED AND SELECTED

Movements Considered	Selected?
1. Shoulder	
A. Flexion	Yes
B. Extension	Yes
C. Abduction	Yes
D. Internal Rotation	Yes
E. External Rotation	Yes
2. Elbow	
A. Flexion	Yes
3. Radio - Ulnar Joints	
A. Pronation	No
B. Supination	No
4. Wrist Joint	
A. Flexion	No
B. Extension	No
C. Abduction	No
D. Adduction	No
5. Hip	
A. Flexion (knee straight)	Yes
B. Extension (knee straight)	Yes
C. Flexion (knee bent)	Yes
D. Extension (knee bent)	No
E. Abduction	Yes
F. Adduction	Yes
G. Internal Rotation	Yes
H. External Rotation	Yes
6. Knee	
A. Flexion	Yes
7. Ankle Joint	
A. Flexion	No
B. Extension	No
C. Inversion	No
D. Eversion	No
8. Hand	
A. Metacarpophalangeal Flexion	Yes
B. Thumb Abduction	No
C. Thumb Adduction	No
9. Spine	
A. Flexion	Yes
B. Extension	Yes
C. Lateral Flexion	No
10. Cervical Region	
A. Flexion	No
B. Extension	No
C. Lateral Flexion	No

FIGURE I-6
SELECTED ELEMENTARY MOVEMENTS

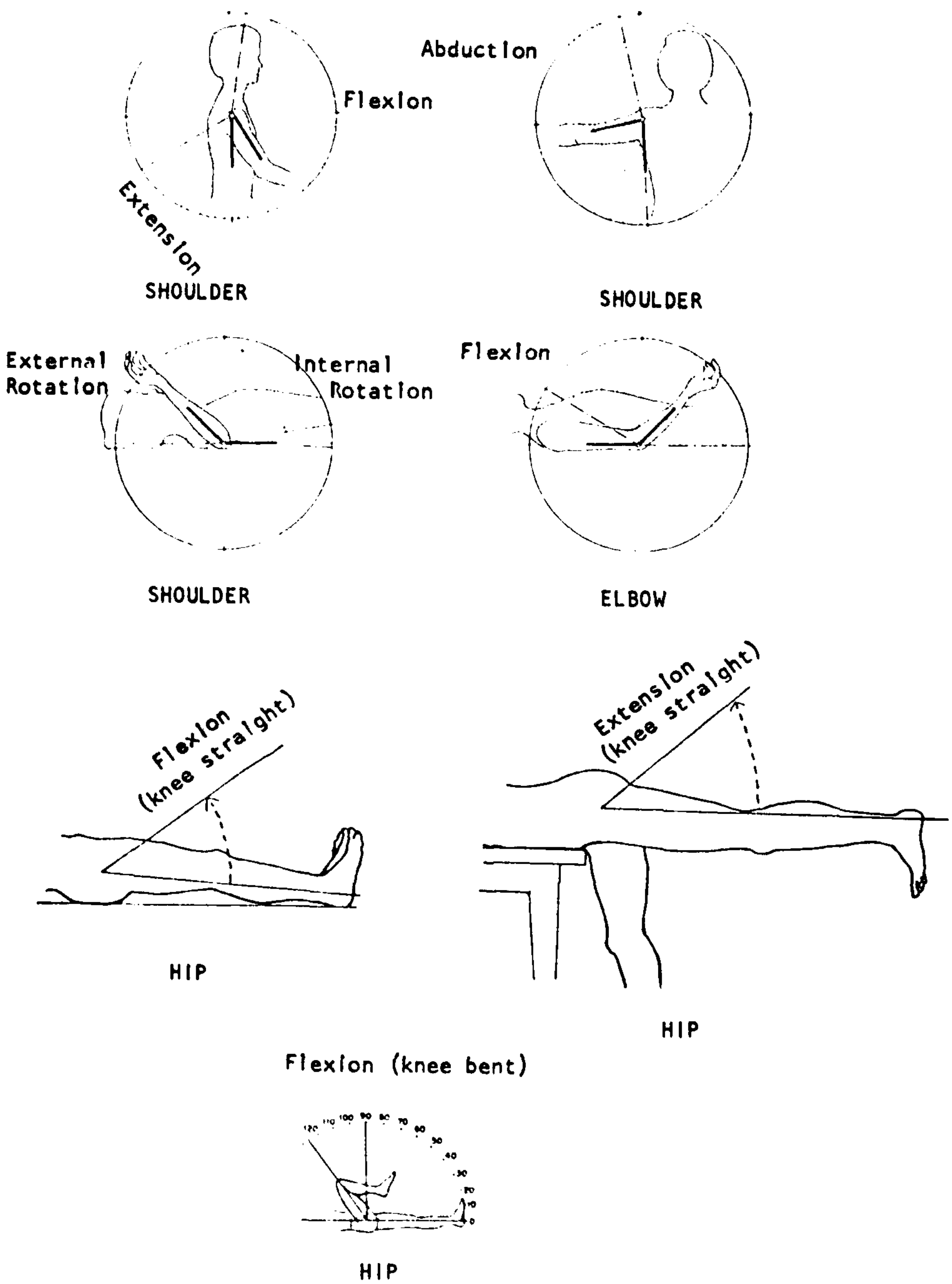
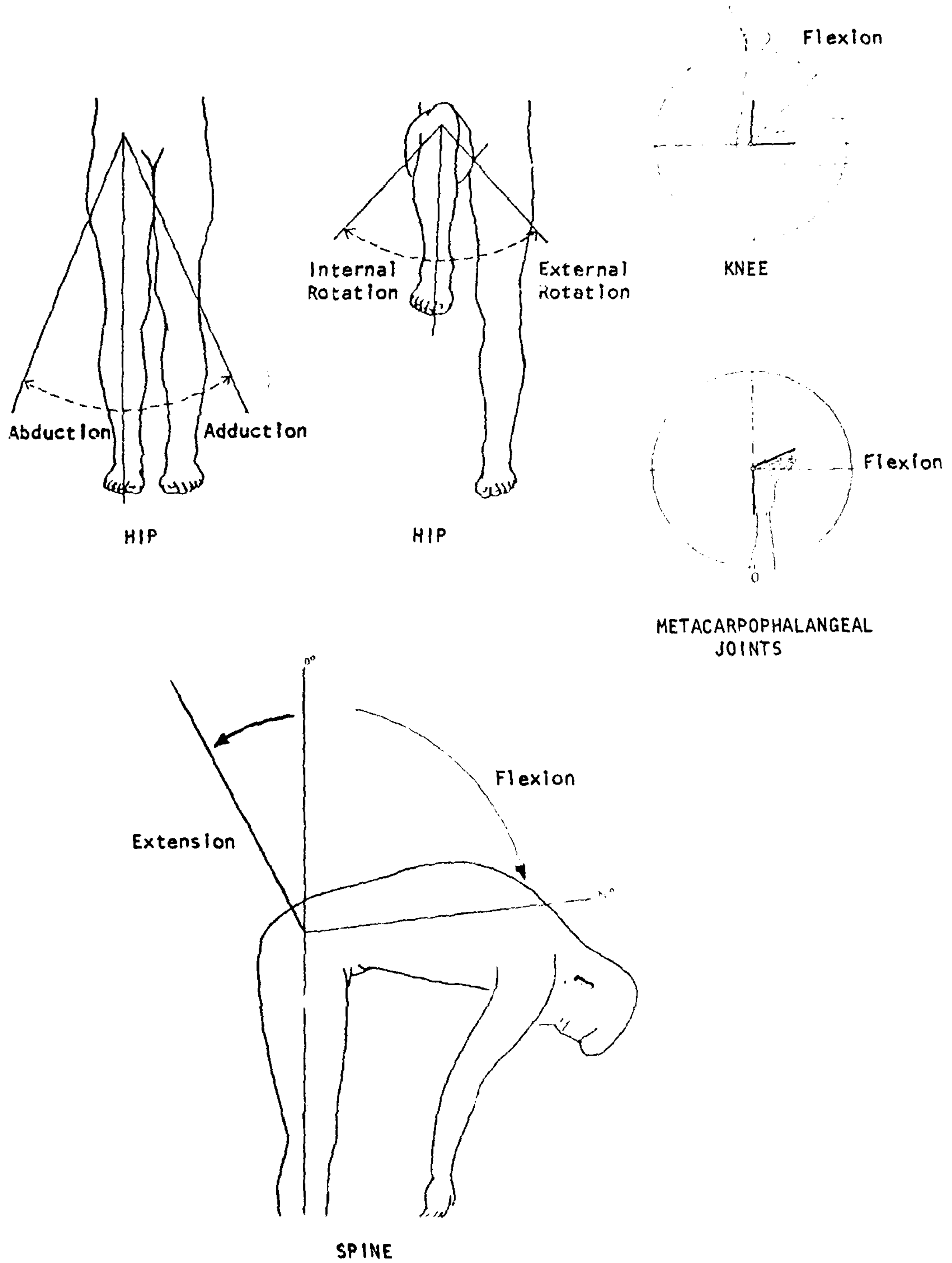


FIGURE I-6 (CONTINUED)
SELECTED ELEMENTARY MOVEMENTS



is a composite showing the elementary movements which were selected for inclusion in the study. Selections were based upon importance of the movements in most physical activity.

The general approach to quantifying the mobility reduction associated with wearing a particular test article was to measure (following the standard procedures outlined in Appendix C) the ranges of motion of test subjects for each selected movement while wearing nominal clothing (the standard work/recreation clothing described in Chapter 2). These measurements were repeated while wearing each of the test articles. The range of motion for each subject and each selected movement in a particular test article was compared to the corresponding range measured in the nominal clothing and the reductions were determined. This approach uses each subject as his own experimental "control". This measurement of ranges of motion was actually the second step of a two-step evaluation procedure.

The first step of the procedure was the subjective evaluation of motion inhibition performed by the test subjects. In this subjective evaluation they assigned an ordinal score depending upon their assessment of each elementary movement as follows.

Score	Definition
0	No interference at all
1	Can achieve full motion with extra effort
2	Slight reduction of motion
3	Moderate reduction of motion
4	Great reduction of motion

This subjective scoring of each movement in each test article was performed for two reasons.

1. It was anticipated that certain articles would not interfere at all with some of the elementary movements (e.g., hip movements) because the range of test articles considered in this investigation included jackets.

2. Extra effort required to perform some movements in some test articles would go unrecognized if the the investigation is based only on measurement of reduced capacity for motion.

While item 2 is conceptually addressed in a separate investigation in (Chapter 5),it was deemed desirable to consider it as well in this comprehensive study of important elementary movements.

Following the subjective scoring, the reduction in motion was determined only for the elementary movements for which subjective scores of 2 or greater were obtained. The reduction of movement was determined by measurement of the ranges of each movement in and out of the test article, as described earlier. A reduction in motion of 0° was assigned to each elementary movement for which a subjective score of 0 or 1 was obtained.

Five test subjects participated in this investigation. Their physical characteristics and normal ranges of motion are described in Table 1-16 These ranges of motion are the averages of three measurements of each joint movement made while the subjects were wearing the standardized work/recreation clothing. An age range of 26 years (21 to 47) is represented. The total intrinsic mobility of each of these subjects, as indicated by the sum of their ranges of motion for the elementary movements, indicates that the oldest subject (FS) did not exhibit the least intrinsic mobility. The suit sizes worn by the test subjects during this investigation are shown in Table 1-17.

A number of the test articles feature either deployable attachments or zippered gussets to increase comfort in the normal mode of wear while retaining cold-protection effectiveness. In general these articles were tested with these devices positioned so as to maximize comfort and mobility in the dry. To avoid any confusion about the modes in which certain of the articles were tested, the following brief descriptions of test conditions are provided.

Test Article	Mobility-Reduction Test Condition
WE1	Diaper stowed, wrist and ankle cinches open, hood off
WE2	Gussets open, beaver tail open, hood off
WE3	Wrist and ankle zippered closures open, hood off
WE4	Beaver tail open, wrist and ankle zippered closures open
WP1	Gussets open, beaver tail stowed, hood off
WP3	Diaper stowed, hood off
WP5	Hood off
WP6	Underliner open,beaver tail stowed,hood off, wrist closures open
DA1	Suit deflated, mitts off, hood off

TABLE I-16
DESCRIPTIONS OF MOBILITY-REDUCTION SUBJECTS

	Attribute \ Subject		MH	MK	JR	FS	SW	MEANS
	Age (years)		25	22	21	47	22	
	Height (cm)		182.7	183.0	178.5	177.8	177.5	
	Weight (kg)		64.1	75.9	60.9	79.4	66.3	
Range of Movement (°) in Normal Clothing	Shoulder	Flex.	156	168	165	164	169	164
		Ext.	50	56	67	64	66	61
		Abd.	180	180	180	180	180	180
		In. Ro.	60	32	62	51	53	52
		Ex. Ro.	90	90	90	90	90	90
	Elbow	Flex.	131	136	139	133	135	135
	Hip	Flex. (st.)	61	74	68	74	61	68
		Ext. (st.)	33	31	21	21	11	23
		Flex. (bent)	97	102	101	100	100	100
		Abd.	33	38	41	29	52	39
		Add.	28	17	25	24	17	22
		In. Ro.	27	41	41	38	40	37
		Ex. Ro.	29	31	49	34	27	34
	Knee	Flex.	122	116	117	116	111	116
	Hand	Flex.	86	93	88	92	87	89
	Spine	Flex.	105	103	105	91	86	98
		Ext.	34	26	38	17	31	29
	TOTAL		1322	1334	1397	1318	1316	1337

TABLE I-17
SIZES OF TEST ARTICLES
USED IN MOBILITY REDUCTION INVESTIGATION

Test Articles \ Subject	MH	MK	JR	FS	SW
WE1	M	M	M	M	M
WE2	M	L	M	M	M
WE3	M	M	M	M	M
WE4	M	L	M	*	M
WP1	M	M	M	M	L
WP2	M	M	M	M	L
WP3	M	M	S	M	M
WP4	MR	LL	LL	MR	MR
WP5	M	M	M	M	M
WP6	S/M	S/M	S/M	S/M	S/M
D1	68-71"	68-71"	68-71"	68-71"	68-71"
D2	40L	-	40L	40L	38R
D3	M	M	M	M	M
DF2	M	M	M	M	M
DA1	X	X	X	X	X

* Subject wore medium pants, large jacket

S = Small
M = Medium
L = Large
S/M = Small/Medium
L/E = Large/Extra Large
MR = Medium, Regular Length
LL = Large, Long Length
38R = 38" Chest, Regular Length
40L = 40" Chest, Long Length
68-71" = 68-71" Height
X = Unsized Prototype

No flotation bladders were inflated and no supplemental flotation devices were worn during this investigation. All closures, other than those listed above, were tested in the closed position.

4.3 Results

The results of this investigation are of two kinds. First the results of the subjective scoring are presented in Table I-18. The cells of this table contain the subjective scores assigned to each elementary movement in each test article by the five test subjects. These scores are in the form of "pentuples" -- sequences of five single-digit scores. They are arranged for the subjects in the order (left to right): MH, MK, JR, FS, and SW. No scores are shown for cells which received five scores of zero. Test article D2 could not be donned by subject MK. The absence of his scores are indicated for that suit by X's.

Scores of I were assigned when full range of motion could be achieved but extra effort was required. Table I-18 indicates in its bottom row the total number of scores of exactly I which were assigned to each of the elementary movements. The eight elementary movements most often indicated to necessitate extra effort to achieve full range of motion are the following.

Elementary Movement	Total No. of I's
Shoulder Flexion	32
Elbow Flexion	32
Shoulder Abduction	26
Hip Flexion (knee bent)	22
Knee Flexion	21
Shoulder Extension	18
Spine Flexion	18
Spine Extension	15

The remaining nine elementary movements are minimally implicated as "extra effort" movements. The reader should keep in mind that full range of motion was achievable when each of these scores of I was assigned. Table I-18 also indicates that the seven test articles most implicated in necessitating extra effort to achieve full range of motion are the following.

Code	Test Article Description	No. I's Per Subject
WE4	White Stag Nylon-Two Wet Suit	5.8
WP4	NADC Modified Wet Suit	5.6
D2	NADC Goretex Experimental Coverall	4.5
WE2	Henderson Zip-On Exposure Suit	4.4
DAI	ILC Industries Prototype Survival Suit	3.8
WEI	Bayley WeatherMate Plus	3.4
WPI	Henderson Prototype Jacket	3.2

TABLE I-18
SUBJECTIVE SCORING OF MOBILITY REDUCTION

Test Article	ELEMENTARY MOVEMENTS																	No. 1's / No. Subjects
	SHOULDER					ELBOW	HIP							KNEE	HAND	SPINE		
	Flex.	Ext.	Abd.	In.Ro.	Ex.Ro.	Flex.	Flex. (st.)	Flex. (st.)	Flex. (bent)	Abd.	Add.	In.Ro.	Ex.Ro.	Flex.	Flex.	Flex.	Ext.	
WE1	01001	00011		10000		10110	00001		10222	00001			00001	10201		10001	00001	3.4
WE2	00001	00110	10000	00001		20111	10000	10000	20111		10000			20101	10111	10001		4.4
WE3	00101	00100	00101			10100			10112					10001		10001	00001	3.0
WE4	10101	10211	10100			20111	10000	10000	21121	11011	10000			10111		10001	10001	5.8
WP1	11111	10110	10101			11111												3.2
WP2	02112	00111	01122						00001		10000					11101	12001	3.0
WP3		00010				00110												0.6
WP4	12121	00101	21131			11010		10001	11122	00010	00101	00001		10101		10001	11001	5.6
WP5		00001				11100												0.8
WP6	01001		00001			10100												1.0
D1	11011		11011						10001									2.0
D2	1X113	0X000	3X111	0X000	0X000	1X100	0X000	1X000	3X333	0X000	0X001	0X001	0X000	1X101	0X000	2X311	1X001	4.5
D3																		0.0
DF2	00010		00010			10110			11112					10101		10000	10100	3.0
DA1	11011		11011			10000	00010		13122			01001		01100		20001	10001	3.8
No. 1's	32	18	26	2	0	32	4	5	22	6	6	4	1	21	4	18	15	

Cells contain subjects' scores (left to right) MH, MK, JR, FS, SW.

Empty cells contain all zeros.

X indicates subject did not score test article.

The subjective scorings in Table I-18 provided guidance in addressing the attribute of the test articles which is the primary concern of this investigation -- reductions in mobility. The subjective scoring obviated the necessity for measuring, and including in the analysis, reductions in mobility which are so small as to be masked by measurement error. Reductions in range of motion were determined for the elementary movements receiving a subjective score of 2 or greater. Subjective scores of 0 or 1, by definition, indicate a 0-degree reduction in joint motion. The results obtained for each elementary movement in each test article constitute a sample of 5 observations of reduction in range of motion. The means of these samples and their standard errors are given in Table I-19.

4.4 Analysis and Discussion

The borders of this table show the totals of these means for each elementary movement and each test article. The movements indicated to be most inhibited, by all the test articles collectively, are the following.

Elementary Movement	Total of Mean Reduction(°)
Hip Flexion (knee bent)	89
Shoulder Abduction	42
Shoulder Flexion	35

These three movements were among the top four (order reversed) indicated earlier to require extra effort to achieve full range of motion. The reversal of their ordering in these lists is consistent with the mutually-exclusive nature of these two analyses (a subject cannot indicate extra effort to be required to achieve full range of a movement and simultaneously indicate reduced movement). That these three movements ranked high in both lists indicates the considerable extent to which they are inhibited by the test articles collectively.

The test articles indicated in Table I-19 to inhibit mobility are the following.

Code	Test Article Description	Total Mean Reduction(°)
D2	NADC Goretex Experimental Coverall	57
WP4	NADC Modified Wet Suit	41
WP2	Medalist Ski Shorty	28
WE1	Bayley WeatherMate Plus	20
DA1	ILC Industries Prototype Survival Suit	18
WE2	Henderson Zip-On Exposure Suit	11
WE4	White Stag Nylon-Two Wet Suit	10
WE3	Stearns Heavy-Duty Offshore Survival Suit	6
DF2	Helly-Hansen Survival Suit	3

TABLE 1-19
SUMMARY OF MOVEMENT REDUCTIONS: MEANS AND (S.E.M.)'s IN DEGREES

Note: Empty Cells have zero mean and (S.E.M.)

Test Article	ELEMENTARY MOVEMENTS																	TOTALS
	SHOULDER					ELBOW	HIP							KNEE	HAND	SPINE		
	Flex.	Ext.	Abd.	In Ro.	Ex.Ro.	Flex.	Flex. (st)	Flex. (st)	Flex. (bent)	Abd.	Add.	In.Ro.	Ex.Ro.	Flex.	Flex.	Flex.	Ext.	
WE1									17 (7)					3 (3)		-		20
WE2						2 (2)			5 (5)					4 (4)				11
WE3									6 (6)									6
WE4		2 (2)				2 (2)			6 (4)									10
WP1																		0
WP2	11 (7)		15 (9)														2 (2)	28
WP3																		0
WP4	16 (10)		17 (14)						8 (5)									41
WP5																		0
WP6																		0
D1																		0
D2	8 (8)		10 (10)						30 (4)							9 (5)		57
D3																		0
DF2									3 (3)									3
DA1									14 (6)							4 (4)		18
TOTALS	35	2	42	0	0	4	0	0	89	0	0	0	0	7	0	13	2	

Ranking the test articles on the basis of mean reduction in motion totaled over the movements considered assumes that all the movements are equally important (uniformly weighted). Of course, this might not be true for a particular intended use. For example, in a certain job, squatting (a combination of hip flexion with knee bent and knee flexion) could be very important while shoulder flexion is unimportant. For this job, WEI would not be as appropriate, on the basis of mobility reduction alone, as WP4 even though WEI is less inhibiting overall. This kind of analysis for particular specific jobs is not the subject of this report. However, this analysis may easily be done using the data given in Tables 1-18 and 1-19.

5.0 FATIGUE-INDUCTION INVESTIGATION

Many of the cold-protection articles tested in this study are designed to be worn by individuals while pursuing their normal duties or activities. It is conceivable that the cold-protection features of these articles may reduce the ability to do useful work by inducing fatigue in the wearer. Therefore, in this section, the fatiguing effect of these articles is addressed.

5.1 *Objectives*

An objective of this study is to quantify and compare the propensities of several constant-wear, cold-protection articles to induce fatigue in the wearer. In other words, how much more tiring is one article to wear than another. The standard work/recreation clothing is used as the basis of comparison. A second objective is to determine the increase in skin surface temperatures resulting from wearing these articles.

Probably the two most important elements of fatigue associated with the wearing of a cold-protection article are first, the increase in energy expenditure resulting from wearing the article and second, the increase in temperature that an individual would experience due to the insulating effect of the article. This would be especially important to military aircraft or boat crewmen who must wear cold-protection articles while on duty over cold-water, regardless of the ambient air temperature. Increased energy expenditure can result from the added weight of the article, from any motion constraining characteristics of it or from both. Increased environmental temperature has been shown (Bell, et al., 1964) to have a detrimental effect on vigilance and mental tasks. It has been shown in data summarized by Simonson (1971, p. 332) that work output of individuals decreases as heat stress increases. Therefore the increases in energy expenditure and body temperature associated with these articles are examined in this study.

5.2 Methodology

The increased workload associated with wearing the cold-protection articles could be assessed most directly by measurement of oxygen use and

carbon dioxide elimination per unit of time in test subjects wearing the test articles. Knowing these parameters the respiratory quotient could be found. The type of food substrate being oxidized could then be determined and the energy expenditure calculated. Oxygen consumption itself can be used to imply energy expenditure if one assumes a constant respiratory quotient. The linear correlation of exercising heart rate with the rate of oxygen use (Shephard, 1969, page 62, and Astrand and Rodahl, 1977, page 349 and 357) has been well established. This plus the fact that the experimental procedure was for the subjects to serve as their own controls, indicates that heart-rate measurements could be used to infer the increase in energy expenditure associated with wearing the test articles. For a given activity, heart rate increases as environmental temperature goes up. Thus heart rate should indicate both the increase in energy expenditure associated with wearing a suit and the increase in micro-environmental temperature that the body sees inside the article.

It would be impossible to predict the exact working activities of all individuals who might wear the cold-protection articles. Therefore, it was decided to test the articles with subjects engaged in three levels of exercise from which various working activities could be implied. The first exercise was sitting. The second exercise was touching the toes, and the third was stair climbing. The first exercise could be used to model a sedentary type of activity such as flying an aircraft. The second, an exercise which involves mostly upper body motion, and the third exercise which involves mostly lower body motion, could be used to model more strenuous types of activities.

The sitting exercise consisted of resting in a chair for a 30 minute period. Studying or quiet talking was allowed. Body movement was kept at a minimum.

The toe-touching exercise was done at a rate of 30 toe touches per minute. Subjects were not actually required to touch their toes but rather only extend to a comfortable level, about ankle height for most.

The stair-climbing exercise was done on two nine-inch stairs. Subjects climbed up and down the stairs always in a forward facing position. One repetition was accomplished with six paces or foot placements. A rate of 100 paces per minute was used for this exercise.

For both exercises the rate was controlled by an electronic metronome. These rates were chosen to achieve two different levels of energy expenditure.

The subjects did the above exercises for seven days before the actual experiments started. Descriptions of the five test subjects participating in this investigation are shown in Table 1-20.

TABLE 1-20
DESCRIPTIONS OF FATIGUE INDUCTION SUBJECTS

Subject	Age	Height (cm)	Weight (kg)
KB	21	177.8	70.0
MM	22	175.0	65.9
RM	24	168.3	63.6
SW	22	177.5	66.3
TW	23	177.0	74.5

Only one experiment per subject was done each day. This avoided any residual fatiguing effect that might be encountered with multiple experiments in one day. Experiments were carried out on consecutive days at the same time of day for each subject. The same prohibitions against medications, alcohol, food and tobacco were placed on the subjects as for the cold-immersion investigation (described in Chapter 3). The correct size article for each subject was determined at the beginning of the experiment. The subject was next instrumented and then dressed in the appropriate attire for that experiment. Table 1-21 shows the size suit each individual wore. Table 1-22 shows the manner in which the articles were tested. No flotation bladders were inflated and no supplemental flotation devices were worn. All closures, other than those listed in Table 1-22 were tested in the closed position.

Shown in Table 1-23 are the total weight of the ensemble as worn by the subjects. This includes the weight of the canvas-top sneakers which were worn with all suits. These experiments were carried out in a room which had an average temperature of 22.4^{0}C with a standard deviation of 2.0^{0}C. The relative humidity averaged 57.5 percent with a standard deviation of 7.3 percent. Following application of the instrumentation, the subjects rested for 30 minutes. Next they performed 5 minutes of the toe-touching exercise followed immediately by 5 minutes of the stair-climbing exercise. Heart rates and skin temperatures were recorded at the 27th, 28th and 29th minute of the sitting period, the 4th and 5th minute of toe-touching, and the 4th and 5th minute of the stair-climbing exercise (see Figure 1-7). An average heart rate and skin

TABLE I-21

SIZES OF TEST ARTICLES USED IN FATIGUE-INDUCTION INVESTIGATION

Test Article \ Subject	KB	MM	RM	SW	TW
WE1	M	M	M	M	M
WE2	L	M	M	M	L
WE3	M	M	M	M	M
WE4	L	M	M	M	L
WP1	L	M	M	L	L
WP2	M	M	M	M	M
WP3	S	S	S	S	S
WP4	MR	MR	MR	MR	MR
WP5	M	M	M	M	M
WP6	S/M	S/M	S/M	S/M	S/M
D1	68-71"	68-71"	68-71"	68-71"	68-71"
D2	40L	38R	38R	38R	40L
D3	M	M	M	M	M
DF2	M	M	M	M	M
DA1	X	X	X	X	X

S = Small
M = Medium
L = Large
38R = 38" Chest, Regular Length
40L = 40" Chest, Long Length
S/M = Small/Medium
X = Unsized Prototype
68-71" = Height in Inches

TABLE I-22
TEST CONDITIONS FOR TEST ARTICLES

Test Article	Fatigue Induction Test Conditions
WE1	Diaper stowed, wrist and ankle cinches open, hood off
WE2	Gussets open, beaver tail open, hood off
WE3	Wrist and ankle zippered closures open, hood off
WE4	Beaver tail open, wrist and ankle zippered closures open
WP1	Gussets open, beaver tail stowed, hood off
WP3	Diaper stowed, hood off
WP5	Hood off
WP6	Underliner open, beaver tail stowed, hood off, wrist closures open
DA1	Suit deflated, mitts off, hood off.

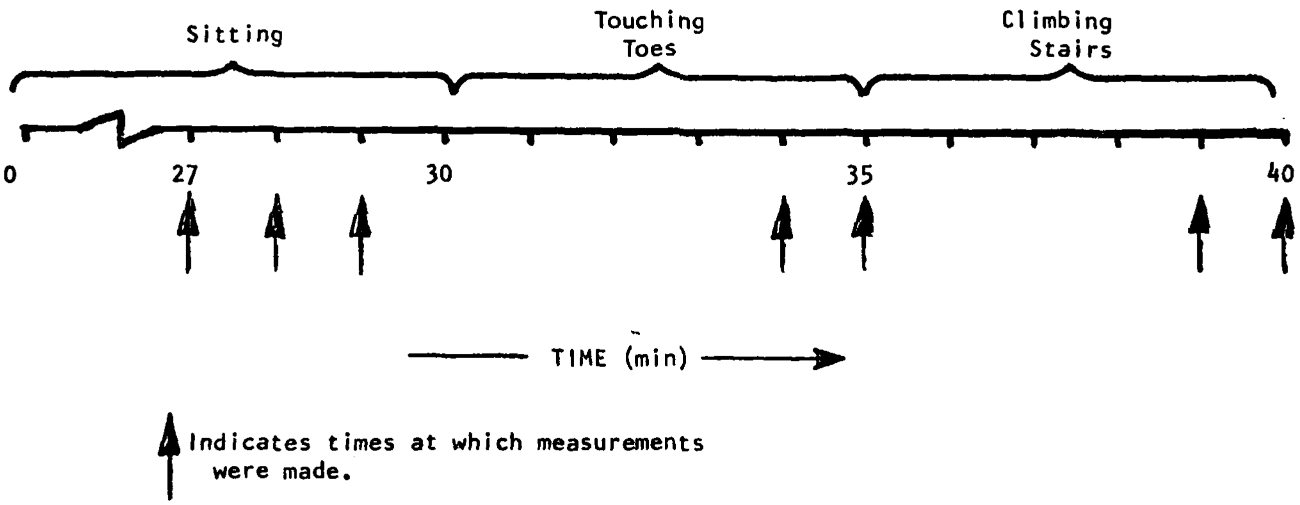
TABLE I-23
WEIGHTS OF TEST ARTICLES †

Article	Weight (kg)
WE1	4.40
WE2	4.45
WE3	4.40
WE4	3.75
WP1	4.37
WP2	2.90
WP3	3.34
WP4	3.60
WP5	3.17
WP6	4.45
D1	4.15
D2	2.68
D3	2.77
DF2	5.60
DA1	4.67

† Size medium was used for all articles with multiple sizes except WP3 for which all subjects were a size small

FIGURE I-7

FATIGUE INDUCTION MEASUREMENT SEQUENCE



temperature for each location was obtained for each activity. Three measurements were made at the end of the sitting period due to the variability of the resting heart rate.

For each subject two experiments were conducted with only the standard work/recreation clothing described in Chapter 2. The articles were then tested on subsequent days and a final experiment using only the standard work/recreation clothing was conducted after all articles were tested.

The heart rate of each subject was monitored with a Zenith system 808 electrocardiogram display unit and strip chart recorder. A lead placement scheme was used which reduces muscle artifact (Blackburn, et al., 1967). The "right-arm" lead was placed over the sternum, the "left-leg" lead was placed at the bottom of the left rib cage and the "right-leg" lead (the indifferent lead) was placed on the back over the third thoracic vertebra. The "lead II" position of the monitoring unit was then used. Standard reusable electrodes were taped to the above mentioned positions.

The temperature monitoring instrumentation used was that described in Section 3.2. The three skin temperatures monitored were at the mid-thigh of the left leg, the mid-forearm of left arm and right subscapula.

5.3 Results

To determine the relative propensities of the cold-protection articles to induce fatigue in the wearer, the percent increase in heart rate for each article and each subject was calculated for the three exercises (sitting, touching toes, and stair climbing). For each exercise this percentage increase was based on the lowest heart rate that a given subject exhibited during the three experiments in normal clothing. These generally occurred during either the second or third normal experiment. In only one case, that of a resting heart rate, was the heart rate lower during the first normal experiment. The average heart rate for sitting was 67.6, for touching toes was 100.7 and for stair climbing was 125.7 beats per minute.

There was not an obvious or statistically significant change in the heart [illegible] observed in the second and third experiments in the standard clothing. [illegible] that all significant training occurred during the 7 days of ex- [illegible] to the start of the experiments.

An average percent change in heart rate for each article and activity was calculated and is presented in Table I-24. The standard error is also shown for each mean. Those entries which have negative signs indicate that the mean heart rate was less for that test article and condition than for the standard clothing. However, these negative differences are not statistically significant at any reasonable level of significance (say 0.10). Therefore, the correct interpretation of the results for these suits is that they are equally fatiguing as the standard clothing ensemble. One should not conclude that these reduce fatigue. This is clearly the case for articles WP5 and WP6 which are worn with the standard clothing underneath.

The results obtained in measuring skin temperatures are expressed in terms of mean elevations in skin temperature and are shown with their standard errors in Table I-25. Weighted averaging over the three temperature sites for each subject was done as follows:

$$\bar{T} = .42\ T_s + .39\ T_t + .19\ T_f$$

Where T_s = subscapular temperature

T_t = thigh temperature

T_f = forearm temperature

The three weighting factors were derived from Hardy and BuBois (1938) and indicate the proportional distribution of surface area between the torso (including the head), legs and arms, respectively. Mean increases in temperature were determined by subtracting the mean temperatures in the standard clothing from the corresponding mean temperatures in the test articles.

5.4 Analysis and Discussion

The large standard errors of the means shown in Table I-24 indicate the difficulty of directly comparing all the suits. However, general differences between types of articles do become apparent. For example, article DF2 causes the largest increase in heart rate for all activities, indicating that it is probably the most fatiguing article. Table I-23 also shows that this article weighs the most, further supporting the heart rate data. The wet-mode articles WE1, WE2 and WE4 and WP1 also show large percentage increases in heart rate for the three activities. These articles were also among the heaviest as indicated by Table I-23. The jackets WP3, WP5, and WP6 cause only slight

TABLE I-24
PERCENT HEART RATES INCREASES
FOR THE THREE EXPERIMENTAL EXERCISES

Exercises / Suit	SITTING		TOE TOUCHING		STAIR CLIMBING	
	Mean	S.E.M.	Mean	S.E.M.	Mean	S.E.M.
WE1	13.04	8.35	4.19	5.72	12.24	4.41
WE2	12.48	7.17	9.66	5.11	14.59	4.01
WE3	3.69	5.07	3.47	6.62	5.39	4.07
WE4	2.16	5.70	9.74	2.10	14.69	3.47
WP1	18.17	3.77	8.87	2.46	11.51	1.97
WP2	6.66	4.42	0.87	3.16	4.56	3.55
WP3	7.39	4.03	-0.32	2.65	3.83	4.80
WP4	4.28	5.86	1.14	3.39	10.44	3.39
WP5	4.55	4.60	-3.37	3.23	1.59	2.32
WP6	6.09	7.15	-2.34	2.74	1.46	3.41
D1	15.22	9.91	-0.36	7.85	10.70	4.13
D2	12.26	7.02	2.20	7.50	6.10	3.88
D3	8.32	2.54	-0.03	2.59	1.25	4.07
DF2	23.76	4.45	11.47	3.75	21.95	2.89
DA1	15.82	4.39	7.94	4.28	10.62	3.65

TABLE I-25

TEMPERATURE † INCREASES
FOR THE THREE EXPERIMENTAL EXERCISES

Test Article \ Exercises	SITTING		TOE TOUCHING		STAIR CLIMBING	
	Mean	S.E.M.	Mean	S.E.M.	Mean	S.E.M.
WE1	1.92	.35	2.30	.25	2.94	.45
WE2	1.40	.28	2.06	.34	2.72	.42
WE3	1.58	.22	2.08	.26	2.70	.34
WE4	1.92	.37	2.66	.41	3.28	.44
WP1	1.04	.39	1.52	.36	1.74	.43
WP2	1.00	.38	1.38	.34	1.88	.36
WP3	0.96	.32	1.16	.41	1.50	.46
WP4	1.38	.30	2.08	.31	2.58	.40
WP5	1.02	.24	0.96	.34	1.06	.46
WP6	1.28	.25	1.50	.34	1.80	.36
D1	0.84	.10	1.34	.12	1.52	.20
D2	0.64	.22	0.90	.19	0.76	.17
D3	0.64	.26	0.98	.29	0.82	.30
DF2	1.86	.28	2.68	.33	3.56	.27
DA1	1.46	.31	1.82	.27	2.10	.34

† Temperatures in °C.

elevations in heart rate and indicate as might be expected that these articles are not very fatiguing to the wearer. The "dry" articles D1, D2 and D3 which are worn with nomex underneath appear to cause little fatigue especially in the two active types of test exercises.

Different jobs require differing amounts of activity and exertion on the part of the individual. Therefore, in order to address this situation, five basic types of activities have been postulated for which the fatigue-induction implications of the test articles could be evaluated. These activity types represent: uncertain activity, general vigorous activity, general sedentary activity, mostly upper-body activity and mostly lower-body activity. These activities are described by the weighting factors shown in Table I-26.

TABLE I-26
WEIGHTING FACTORS OF THE FIVE ACTIVITY MODELS

Number	Physical Activity	Sitting	Toe Touching	Stair Climbing
1	Uncertain	.33	.33	.33
2	Generally Active	.10	.45	.45
3	Sedentary	.80	.10	.10
4	Mostly Upper Body movement	.10	.80	.10
5	Mostly Lower Body movement	.10	.10	.80

The weighting factors were assigned to sum to 1.0 for each activity model and to utilize a value of .10 for each exercise which is of little importance in each type of activity being modeled. The remaining factors were assigned values uniformly within each model.

Weighted-average percent increases in heart rate have been computed with these weighting factors and are shown for each activity in Table I-27. The rankings of the test articles, in order of increasing fatigue, for each type of activity is shown in Table I-28. It may be seen that WP5 is uniformly least fatiguing while DF2 is uniformly the most fatiguing of the test articles considered in this investigation. The only two test articles whose ranking depends greatly upon the nature of the activity for which it is to be used are WE4 (ranked 13th under activity model 2 but 3rd under activity model 3) and D3 (ranked 3rd under activity model 2 but 8th under activity model 3). Other test articles can be seen to vary much less widely in their ranking

TABLE I-27
WEIGHTED MEAN PERCENT INCREASE IN HEART RATE

Test Article \ Activity Model	1	2	3	4	5
WE1	9.82	8.70	12.08	5.88	11.52
WE2	12.24	12.16	12.41	10.44	13.89
WE3	4.18	4.36	3.84	3.68	5.03
WE4	8.86	11.21	4.17	9.48	12.94
WP1	12.85	10.99	16.57	10.06	11.91
WP2	4.03	3.11	5.87	1.82	4.40
WP3	3.63	2.32	6.26	0.87	3.77
WP4	5.29	5.64	4.58	2.39	8.89
WP5	0.92	-0.35	3.46	-2.08	1.39
WP6	1.74	0.21	4.78	-1.12	1.54
D1	8.52	6.18	13.21	2.30	10.05
D2	6.85	4.96	10.64	3.60	6.33
D3	3.18	1.38	6.78	0.93	1.83
DF2	19.06	17.42	22.35	13.75	21.08
DA1	11.46	9.93	14.51	8.99	10.87

TABLE I-28

RANKING OF TEST ARTICLES BY MEAN PERCENT HEART RATE INCREASE FOR FIVE ACTIVITY MODELS

Ranking \ Activity Model	1	2	3	4	5
1	WP5	WP5	WP5	WP5	WP5
2	WP6	WP6	WE3	WP6	WP6
3	D3	D3	WE4	WP3	D3
4	WP3	WP3	WP4	D3	WP3
5	WP2	WP2	WP6	WP2	WP2
6	WE3	WE3	WP2	D1	WE3
7	WP4	D2	WP3	WP4	D2
8	D2	WP4	D3	D2	WP4
9	D1	D1	D2	WE3	D1
10	WE4	WE1	WE1	WE1	DA1
11	WE1	DA1	WE2	DA1	WE1
12	DA1	WP1	D1	WE4	WP1
13	WE2	WE4	DA1	WP1	WE4
14	WP1	WE2	WP1	WE2	WE2
15	DF2	DF2	DF2	DF2	DF2

(e.g., WP2 varies from 5th to 6th, D2 varies from 7th to 8th and WE1 varies from 10th to 11th). Therefore, it is concluded that the fatigue-induction properties of the test articles are not strongly dependent upon the specific nature of the activity to be performed.

Table 1-29 shows the statistical significances of the differences among the mean percent increases in heart rate under activity model 1. The table shows the levels at which the mean increases with the test articles indicated by the rows are significantly superior to (smaller than) the mean increase with the article indicated by the column. These levels of significance were determined by an approximate t-test employing Satterthwaite's approximation for degrees of freedom. The only assumption invoked for this analysis is that the random variation in heart rate changes is normally distributed.

The analysis of the propensities of the test articles to over-heat the wearer is based on activity model 1 (uniform weighting of results from the three exercises). The mean increases in the weighted average skin surface temperature is shown for each test article in Table 1-30. The test articles have been ranked in order of increasing elevations in skin temperature. Article DF2 has the largest mean temperature increase, reinforcing the fact that it was the most fatiguing of those articles tested. The wet-mode, entire-body articles (WE1, WE2, WE3 and WE4) tend to rank next in causing large surface temperature increases. The dry suits (D1, D2, and D3) cause relatively small increases in mean skin temperature, with the double-layered entile, D1, causing more than the single-layered D3 or goretex D2. The rest of the articles tend to fall between these extremes. Table 1-31 shows comparisons among the surface temperature elevations similar to those shown for heart rate data in Table 1-29.

TABLE I-29
COMPARISONS AMONG MEAN HEART RATE INCREASES
FOR THE TEST SUBJECTS

Superior Test Article \ Inferior Test Article	WP5	WP6	D3	WP3	WP2	WE3	WP4	D2	D1	WE4	WE1	DA1	WE2	WP1	DF2
WP5	-	.44	.22	.27	.25	.29	.19	.20	.18	.04	.11	.03	.03	.01	.01
WP6		-	.31	.37	.33	.35	.27	.25	.22	.09	.15	.06	.05	.03	.01
D3			-	.42	.49	.50	.41	.35	.29	.13	.21	.08	.08	.02	.01
WP3				-	.44	.44	.34	.30	.26	.08	.18	.06	.06	.01	.01
WP2					-	.49	.40	.34	.29	.14	.21	.09	.08	.03	.01
WE3						-	.43	.36	.31	.21	.24	.13	.12	.08	.02
WP4							-	.41	.35	.22	.27	.14	.12	.06	.01
D2								-	.43	.38	.37	.27	.23	.19	.06
D1									-	.48	.44	.36	.32	.29	.11
WE4										-	.44	.30	.25	.15	.02
WE1											-	.41	.36	.33	.11
DA1												-	.43	.38	.09
WE2													-	.47	.14
WP1														-	.09
DF2															-

TABLE I-30
INCREASES IN WEIGHTED AVERAGE
SKIN SURFACE TEMPERATURE

Rank	Test Article	Mean † Increase In Surface Temperature (°C)
1	D2	.77
2	D3	.81
3	WP5	1.01
4	WP3	1.21
5	D1	1.23
6	WP2	1.42
7	WP1	1.43
8	WP6	1.53
9	DA1	1.79
10	WP4	2.01
11	WE2	2.06
12	WE3	2.12
13	WE1	2.39
14	WE4	2.62
15	DF2	2.70

† Means computed using activity model 1.

TABLE I-31
COMPARISONS AMONG MEAN SURFACE TEMPERATURE
INCREASES FOR THE TEST SUBJECTS

Superior Test Article \ Inferior Test Article	D2	D3	WP5	WP3	D1	WP2	WP1	WP6	DA1	WP4	WE2	WE3	WE1	WE4	DF2
D2	-	.45	.26	.17	.03	.08	.08	.04	.01	.01	.01	.01	.01	.01	.01
D3		-	.33	.22	.11	.11	.11	.06	.02	.01	.01	.01	.01	.01	.01
WP5			-	.36	.28	.21	.21	.15	.06	.03	.03	.02	.01	.01	.01
WP3				-	.47	.35	.32	.27	.14	.08	.07	.05	.02	.02	.01
D1					-	.32	.32	.21	.07	.04	.04	.01	.01	.01	.01
WP2						-	.49	.41	.22	.13	.12	.08	.04	.03	.01
WP1							-	.43	.24	.14	.13	.09	.05	.03	.02
WP6								-	.28	.15	.14	.09	.05	.03	.01
DA1									-	.33	.29	.23	.12	.07	.03
WP4										-	.46	.40	.23	.12	.08
WE2											-	.45	.26	.13	.10
WE3												-	.28	.13	.09
WE1													-	.27	.25
WE4														-	.45
DF2															-

6.0 EASE OF DONNING INVESTIGATION

As mentioned in Chapter I, the rapidity with which items of equipment intended to provide protection against hypothermia can be donned is of considerable interest to a variety of groups. These include search and rescue boat and aircraft crews, tactical aircraft crews, merchant mariners on sinking ships and individuals who find themselves accidentally immersed with protection equipment accessible to them.

6.1 Objectives

This investigation was formulated to determine the ease with which the various test articles can be donned in and out of water. No dry suits (D, DF or DA) were tested for ease of donning in the water. In addition, it was desired that the tests reveal the potential significance of practice and equipment familiarization to the rapidity with which an individual can don these devices. It was also desired that this investigation identify specific design problem areas which had relatively large impact on the donning of the test articles. Test article DA2 was not included in this investigation. Donning times with it would be quite long; and it is not clear that an unassisted individual could don it without practice.

6.2 Methodology

The general methodology used in this investigation was to conduct a two-phase, timed donning trial using different subjects for the water and land donnings of each selected suit. The first phase addressed donning with minimal familiarization. The second phase was performed after a leisurely period of equipment familiarization which followed the first donning trial. Different subjects were used for the water and land donnings of each particular test article to eliminate the effects of any specific learning which would have occurred during the first test condition.

General Protocol

The sequence of events for a land or water donning was as follows. First, the subjects received an introductory briefing during which the following points were made.

1. "You are about to conduct a timed donning trial. You will be given 60 seconds to examine the suit before you begin.

2. You should work at your fastest productive speed. The trial will not be terminated until the suit is donned properly and completely -- all closures closed.

3. After this first trial we will familiarize you with the suit and answer any questions you may have. Then we will repeat the timed trial."

No instructions or suggestions were given as to how to don the suits, even if it was obvious that the subject was proceeding incorrectly. If something was incomplete or improperly done at the time the subject indicated he was finished, he was told what was wrong and the recording of time was continued until the problems were remedied. Descriptions were recorded of the specific deficiencies which existed at the time the subject first indicated he was finished.

The suits were presented to the subject in their normal carrying case, if they came with one, or in a general-purpose, zippered, gear bag. Any manufacturer-supplied donning instructions were included with the suit.

The characteristics of the subjects participating in the donning exercises are listed in Table I-32. These subjects participated in donnings on land or in water but not necessarily in both.

Donnings on Land

The donnings on land were conducted in a closed laboratory. Ambient air temperature was generally around 22°C. The subjects donning the various test articles on land and the suit sizes they wore are listed in Table I-33. Each article was donned by five different subjects.

The complete ensembles described in Chapter 2 were donned in this investigation with the following exceptions.

1. Test articles worn over the standard work/recreation clothing were donned with these clothes already in place.
2. No supplemental flotation was donned.
3. No inflatable compartments were inflated during the timed trial.
4. Sneakers were not included in the donnings of WP2, WP4, D1, D2 or D3.

The nomex underwear was included in the materials to be donned with several of the suits. This presented the opportunity for a subject donning more than

TABLE I-32
DESCRIPTIONS OF
DONNING INVESTIGATION SUBJECTS

Subject	Age	Height (cm)	Weight (kg)
JA	23	180.3	68.2
CB	23	185.4	81.8
KB	21	177.8	70.0
JC	21	182.0	88.2
KC	22	185.0	85.4
SC	18	179.7	65.0
GD	30	172.7	70.4
GF	24	178.2	67.3
MF	19	180.3	65.9
JG	21	177.8	63.6
MG	21	165.0	60.9
TH	20	175.3	58.2
MH	25	182.7	64.1
BH	23	178.9	82.7
GH	22	180.3	75.0
JH	21	170.3	70.4
PK	21	183.9	91.4
GK	21	180.3	74.4
MM	22	175.0	65.9
MO	21	180.0	76.4
TP	25	185.2	76.4
HS	20	175.9	74.1
CS	18	177.8	72.7
SW	22	177.5	66.3
TW	23	177.0	74.5

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TABLE I-33

ASSIGNMENT OF SUBJECTS TO TEST ARTICLES
(Donnings On Land)

TEST SUBJECTS	TEST ARTICLES																
	WE1	WE2	WE3	WE4	WP1	WP2	WP3	WP4	WP6	D1	D2	D3	DF1 (neoprene)	DF1 (PFC)	DF2	DF3	DA1
JA										68-71"		M					
CB	M			L		L	L	LL	L/E				X		M		
JC	M	L					L		L/E				X		M		
KC	M	L					L		L/E				X		M		
SC					M					68-71"		M					
GD											38R						
GF			M	M		M		MR						X		M	X
MF										68-71"		M					
JG											40L						X
MG	M	M							S/M								
TH					M						38R						X
BH			M	L		L		LL						X		M	
GH					L					68-71"		M					
JH														X			
PK			M	L			L						X		M	M	
GK					L					68-71"		M					
MO		M	M			M		MR						X		M	
TP	M	L	M			L	L	LL	S/M				X		M	M	
HS					L						38R						X
CS											40L						X
SW				M										X			

S = Small
M = Medium
L = Large

S/M = Small/Medium
L/E = Large/Extra Large
38R = 38" Chest, Regular Length

40L = 40" Chest, Long Length
X = Unsized prototype or one size fits all
68-71" = Height

one of these test articles to learn techniques with the nomex portion which would shorten his time required for that portion of the exercise in later trials. Therefore each subject testing these suits donned the nomex for timing purposes only for the first suit tested. The subjects began all such subsequent donnings with the nomex underwear in place and their times for donning the nomex alone (with and without practice, respectively) were added to the suit-donning times to get total donning times for later trials.

<u>Donnings in Water</u>

Water donnings were conducted in the diving pit of the Clemson University swimming pool. The water temperature was approximately 27°C. Only test subjects who could swim and tread water were allowed to participate in these experiments. Test subjects received essentially the same initial briefing as before donnings on land. Test articles were presented to the test subjects on the deck adjacent to the diving pit. Carrying cases or general-purpose gear bags were used to transport and enclose the test articles. A 60-second period was allowed for the subject to examine the test article before beginning the timed trial. After the examination period, the subject entered the water. The test article was thrown to the subject in the water. The timed trial began when the subject touched the test article.

Test articles which consist of multiple pieces (WE1, WE2, WE4 and WP2) were thrown to the subject one piece at a time to preclude the pieces from dispersing over the water and delaying the donning. Thus all donning times reported in this chapter are times spent in actually working to don the test articles. To eliminate any influence on donning efficiency caused by the order in which the pieces of the multi-piece test articles were donned, the subjects were required to request the pieces in the order that they wanted them.

During donnings in the water subjects were observed from the deck and from under the water. The objective was to provide maximum opportunity to identify specific causes of any difficulty encountered during the donnings. Following the first donning a leisurely equipment familiarization period was provided. The subjects were encouraged to reread any instructions provided by the manufacturer. Particular problems encountered during the first donning were discussed with the subjects.

The articles donned in the water are indicated in Table 1-34 along with

TABLE I-34
ASSIGNMENT OF SUBJECTS TO TEST ARTICLES
(Donnings in Water)

Test Subjects	TEST ARTICLES							
	WE1	WE2	WE3	WE4	WP1	WP2	WP3	WP6
CB		L	M					
KC			M	L		L		
GD					L			
GF	M	M					L	
MF					M			
JG							S	
MH		M	M		M			S/M
JH	M		M			M	L	
PK	M					L		L/E
GK				L	L			
MO	M			L			M	S/M
TP				L				
CS		L						
SW	M	M	M			M	L	S/M
TW				L	L	M		L/E

S = Small
M = Medium
L = Large
S/M = Small/Medium
L/E = Large/Extra Large

the respective subjects and article sizes used. Of course, no dry-mode articles were considered for wet donnings. Also WP4 was omitted since it is a constant-wear device for military flight personnel. Articles WP5 and WP7 were omitted because of the trivial nature of their donning requirements. The remaining test articles in Table I-34 were donned in their entirety (as described in Chapter 2) with the following exceptions.

1. The suits were donned over bathing suits only
2. No supplemental flotation was donned

6.3 Results

Donnings On Land

The results of the donning on land are summarized in Table I-35. The test articles have been ranked in order of increasing mean donning time with practice. It should be noted that only five of the test articles could be donned in about 1 minute or less. Table I-35 shows the reductions (in percent) in mean donning times resulting from equipment familiarization and donning practice and indicates the nine test articles which exhibited differences in mean donning times (with and without practice) statistically significant at the 0.05 level. The reductions in mean donning time range from 7 percent for DF1(neoprene) to 56 percent for DF3. The significances of the reductions were determined with the nonparametric randomization test for two independent samples. Though nonparametric, this test makes use of the interval-level, donning-time data. The use of a non-parametric test was based on the author's agreement with the general notion that task-performance times tend not to follow a Gaussian distribution.

To investigate the statistical significances of the differences in mean donning times among the test articles (within each practice condition), the randomization test was applied to compare each pair of articles which could be selected from those included in the donnings on land. Rather than performing the comparisons at a particular level of significance producing for each a corresponding discrete result (difference either is or is not significant at the chosen level), a more descriptive statistic has been computed. For each pair of test articles, the level of significance has been computed at which the respective mean donning times are significantly

TABLE I-35

TIMES† REQUIRED FOR DONNINGS ON LAND

Test Articles	WITHOUT PRACTICE Mean	WITHOUT PRACTICE S.E.M.	WITH PRACTICE Mean	WITH PRACTICE S.E.M.	Percent Improvement
WE3	0.90	.17	0.76	.10	16
WP2	0.91	.08	0.84	.07	8
DF1 (neoprene)	1.01	.16	0.94	.09	7
WP6 *	1.60	.08	1.05	.03	34
DF3 *	2.39	.38	1.06	.19	56
DF1 (PVC)	1.42	.23	1.17	.29	18
DF2	1.39	.22	1.27	.25	9
WP1 *	2.65	.60	1.28	.06	52
D1 *	1.79	.18	1.32	.11	26
D3 *	1.72	.15	1.37	.10	20
D2 *	2.66	.29	1.50	.10	44
WP4	1.95	.28	1.60	.24	18
WP3 *	3.94	.83	1.79	.30	55
WE1 *	3.06	.44	1.93	.22	37
WE2	3.26	.37	2.63	.28	19
DA1 *	4.37	.43	2.68	.30	39
WE4	4.53	.49	3.76	.53	17

† Times given in minutes

* Differences in mean times with and without practice significant at the 0.05 level

different. These levels of significance are shown for comparisons among donnings without practice in Table I-36 and for donnings with practice in Table I-37. In each table the test articles have been arranged in order of increasing mean donning time. The numbers in the tables are the significance levels at which the test article corresponding to the row is significantly superior to the test article corresponding to the column in terms of mean donning time (superior implies shorter mean donning times). Differences of great significance are indicated by small numbers in these tables. It may be regarded as a positive indication for a test article to have many small numbers in its row and a negative indication for one to have many small numbers in its column. Of course, someone interested only in a subset of the test articles (e.g., dry suits) could consider the differences among them by ignoring the rows and columns corresponding to wet suits.

During the performance of the donnings without practice on land a number of specific difficulties were observed to occur with some frequency. The difficulties which were observed two or more times out of the five replications are listed with their frequencies of occurrence in Table I-38.

Donnings in Water

The results of the donnings in water are summarized in Table I-39. The test articles have been ranked in order of increasing mean donning time with practice. Table I-39 also shows the percent improvements in mean donning time resulting from equipment familiarization and donning practice and indicates the two test articles for which mean donning times were found to be significantly shorter, with practice than without it, at the 0.05 level. The percents improvement in mean donning time range from essentially 0 percent for WE2 to 54 percent for WP3. Statistically significant improvements were found in the water for WP1 and WP3 as they were on land.

Comparisons of the significances of the differences among the test article results obtained in donnings in water have been developed in a manner similar to those previously shown for donnings on land. The comparisons among donnings conducted without practice are shown in Table I-40 and those for donnings conducted with practice are shown in Table I-41.

Specific difficulties which were observed in two or more of the water donnings without practice are listed with their frequency of occurrence in

TABLE I-36
COMPARISONS AMONG DONNINGS
WITHOUT PRACTICE ON LAND

Superior Test Article \ Inferior Test Article	WE3	WP2	DF1 (neo*)	DF2	DF1 (PVC)	WP6	D3	D1	WP4	DF3	WP1	D2	WE1	WE2	WP3	DA1	WE4
WE3	-	.49	.28	.07	.06	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
WP2		-	.33	.03	.04	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
DF1 (neo*)			-	.09	.08	.02	.01	.01	.02	.01	.01	.01	.01	.01	.01	.01	.01
DF2				-	.46	.20	.15	.10	.06	.04	.03	.01	.01	.01	.01	.01	.01
DF1 (PVC)					-	.26	.16	.12	.08	.04	.03	.01	.01	.01	.01	.01	.01
WP6						-	.31	.19	.13	.04	.04	.01	.01	.01	.01	.01	.01
D3							-	.36	.24	.07	.06	.01	.01	.01	.01	.01	.01
D1								-	.29	.09	.10	.02	.02	.01	.01	.01	.01
WP4									-	.18	.18	.07	.04	.02	.02	.01	.01
DF3										-	.38	.31	.13	.08	.07	.01	.01
WP1											-	.49	.31	.19	.12	.03	.02
D2												-	.23	.14	.10	.01	.01
WE1													-	.36	.20	.04	.04
WE2														-	.28	.06	.04
WP3															-	.32	.28
DA1																-	.42
WE4																	-

* neoprene

TABLE I-37
COMPARISONS AMONG DONNINGS
WITH PRACTICE ON LAND

Superior Test Article \ Inferior Test Article	WE3	WP2	DFI (neo*)	WP6	DF3	DFI (PVC)	DF2	WPI	DI	D3	D2	WP4	WP3	WEI	WE2	DAI	WE4
WE3	-	.27	.11	.02	.11	.09	.06	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
WP2		-	.23	.02	.17	.17	.09	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
DFI (neo*)			-	.13	.29	.33	.13	.02	.01	.01	.01	.02	.01	.01	.01	.01	.01
WP6				-	.48	.48	.22	.01	.03	.01	.01	.03	.01	.01	.01	.01	.01
DF3					-	.38	.27	.16	.15	.09	.04	.07	.03	.02	.01	.01	.01
DFI (PVC)						-	.49	.41	.34	.29	.17	.14	.10	.04	.01	.01	.01
DF2							-	.48	.49	.37	.21	.17	.10	.04	.01	.01	.01
WPI								-	.38	.27	.07	.13	.02	.02	.01	.01	.01
DI									-	.38	.15	.17	.06	.04	.01	.01	.01
D3										-	.20	.21	.09	.04	.01	.01	.01
D2											-	.35	.25	.06	.01	.01	.01
WP4												-	.31	.16	.01	.02	.01
WP3													-	.37	.05	.03	.01
WEI														-	.05	.05	.01
WE2															-	.47	.04
DAI																-	.06
WE4																	-

* neoprene

TABLE 1-38
SPECIFIC DIFFICULTIES IN DONNINGS WITHOUT PRACTICE ON LAND

Test Article	Specific Difficulty	Frequency Of Occurrence
WP6	Missed top and bottom snaps on jacket	2
DF3	Did not roll entry	2
DF1 (PVC)	Slight difficulty with hood	3
DF2	Missed face tie	3
WP1	Difficulty with hood closure	2
D3	Zipper stuck	2
WP3	Difficulty finding clips for diaper	3
	Zipper stuck on adjacent loose fabric	3
WE1	Difficulty with velcro closure on diaper	3
	Difficulty with wrist and ankle closures	3
DA1	Difficulty with zip-lock closure	5
	Missed hood	3
WE4	Difficulty with boots and gloves	2

TABLE I- 39
TIMES † REQUIRED FOR DONNINGS IN WATER

Test Articles	WITHOUT PRACTICE Mean	S.E.M.	WITH PRACTICE Mean	S.E.M.	Percent Improvement
WP2	2.15	0.33	1.48	.25	31
WE3	2.55	0.53	1.99	.22	22
WP6	2.91	0.66	2.17	.43	25
WE1	2.80	0,38	2.18	.31	22
WP1 *	3.15	0.23	2.18	.08	31
WP3 *	5.54	1.27	2.57	.34	54
WE4	4.95	0.64	4.29	.75	13
WE2	5.89	0.86	5.88	.68	0

† Times given in minutes

* Differences in mean times with and without practice significant at the 0.05 level

TABLE I-40
COMPARISONS AMONG DONNINGS
WITHOUT PRACTICE IN WATER

Superior Test Article \ Inferior Test Article	WP2	WE3	WE1	WP6	WP1	WE4	WP3	WE2
WP2	-	.26	.12	.17	.02	.01	.02	.01
WE3		-	.36	.30	.13	.02	.04	.01
WE1			-	.45	.22	.01	.05	.01
WP6				-	.38	.03	.06	.02
WP1					-	.02	.07	.02
WE4						-	.34	.19
WP3							-	.41
WE2								-

TABLE I-41
COMPARISONS AMONG DONNINGS
WITH PRACTICE IN WATER

Superior Test Article \ Inferior Test Article	WP2	WE3	WP6	WE1	WP1	WP3	WE4	WE2
WP2	-	.08	.11	.06	.02	.02	.01	.01
WE3		-	.36	.33	.24	.09	.01	.01
WP6			-	.48	.50	.25	.02	.01
WE1				-	.50	.20	.01	.01
WP1					-	.14	.01	.01
WP3						-	.03	.01
WE4							-	.08
WE2								-

TABLE I-42
SPECIFIC DIFFICULTIES IN DONNINGS
WITHOUT PRACTICE IN WATER

Test Articles	Specific Difficulty	Frequency Of Occurrence
WE3	Hood came off	3
WE1	Difficulty with velcro closure on diaper	4
WP1	Beaver tail snaps out of sequence	2
WP3	Difficulty finding clips for diaper	3

Table I-42. The test articles are ranked as they were in Table I-39 to facilitate comparisons.

6.4 Analysis and Discussion

Donnings On Land

It is interesting to note the distribution of the categories of test articles through the ranking shown in Table I-35. Three of the four WE test articles (WE's numbered 1, 2 and 4) were among the last four ranked positions. However, WE3 is in first place indicating extreme variation in donability after practice. The same kind of variation occurred in the first donning as well. The WP-type suits exhibited similar but less extreme variation, ranging from WP2 in second place to WP3 in thirteenth place. By contrast, the two dry types of suits which were represented by multiple suits (D and DF) exhibited much less variability in these results. The four DF suits ranked from third through seventh, while the three D suits ranked from ninth through eleventh.

The improvements in the mean donning times shown result largely from overcoming the specific difficulties, listed in Table I-38, which were experienced during the donning without practice. The absence of information for a particular article in Table I-38 does not mean that no difficulty was experienced in donning it. Rather it means that no specific difficulties were experienced repeatedly. It is not necessarily a negative indication for an article to exhibit multiple specific deficiencies for donning without practice nor a positive indication for one to exhibit none. Such specific deficiencies, once identified, may be easily remedied. General deficiencies may be much more difficult to remedy.

The specific difficulties observed with WP6 resulted from the subjects simply not noticing the small snaps provided to hold the jacket closed. Closing these snaps after prompting during the without-practice trial involved relatively small additional times.

The failure of the two individuals to roll the entry on DF3 is of considerable potential importance. Rolling this entry is necessary to provide a water-tight closure. Allowing water to enter the suit would, of course, defeat a primary design feature of this suit. Failure to roll the entry relates to a general lack of attention given, during the donning

without practice, to the picture-sequence instructions provided to facilitate correct donning. Efforts should be directed toward packaging and marking these instructions to capture the attention of someone donning this suit for the first time in an emergency situation. It should also be noted that the direction in which the entry is rolled may be critical to achieving a water-tight seal. One cold-immersion experiment had to be aborted because the entry leaked. In donning for this particular cold-immersion the entry was rolled forward rather than backward as shown in the picture sequence. If this aspect of donning is that critical, then some emphasis should be placed upon it in the donning instructions.

The face tie, left untied in three donnings of DF2, is intended to reinforce the face seal against water entering the suit. This reinforcement is of greatest importance when entering the water by jumping from some height, say 3 meters. Having the subjects tie it during the donning without practice added a relatively small amount of time.

The difficulty with the hood closure on WP1 resulted primarily from confusion concerning the snap halves permanently attached to the upper chest. They function to hold the points of the jacket collar down retaining the hood in its stowed position. They have no function in closing the hood when in position on the wearer's head, but they distracted the subjects. Equipment familiarization easily overcame this difficulty.

Difficulty in finding the clips to deploy the diaper on WP3 provided major delays in its donning. These clips are hidden in the jacket's front pockets to preserve its appearance. Although mentioned in the donning instructions sewn into the jacket, their location should be emphasized. Equipment familiarization remedied this problem. A problem which is less easily remedied through equipment familiarizalton is the zipper sticking. A thin flap of material is provided to cover the back of the zipper when closed. It is probably intended to retard the rate of seepage of outside water through the zipper. However, the flexibility and thinness of this flap allows it to get under the zipper slide causing a jam. This difficulty could best be eliminated by equipment modification.

The velcro attachment on the diaper of WE1 involves inserting a "tongue" coated with velcro wool on both sides into a "jaw" lined inside, top and bottom, with velcro hooks. This type of attachment was apparently unfamiliar to the subjects. All parts were colored black making it difficult to locate

and identify the jaw. The tongue was difficult to insert fully into the jaw because of the tendency of the velcro parts to attach themselves prematurely. This problem was partially remedied by equipment familiarization. However, design improvements are undoubtedly possible which would aid the first-time user of this suit. Some difficulty was also encountered in operating the cinch-type ankle and wrist closures. This could be reduced by constructing the cinching belts of more pliable webbing and securing the belt so that they can not come unthreaded from their D-ring buckles.

The water-tight closure used on DAI deserves some consideration. It was discovered in donning for cold-immersion experiments that this closure was difficult to close securely. More importantly, it was noticed that it is very difficult to determine when this closure is sealed properly. Great care had to be exercised to achieve a secure seal. In view of the difficulty inherent in detecting improper closure of this device, one would anticipate that some users, donning DAI in a time-critical situation, might overlook an improper seal. The water-tight integrity of this closure, and for that matter all other seals (wrists and neck) as well, is absolutely vital to the functioning of the suit in prolonging survival in cold water. The other difficulty observed with DAI was the omission of donning the inflatable hood which was stowed inside a zippered compartment in the collar. This difficulty was, of course, remedied by equipment familiarization.

Donnings in Water

As with donnings on land, the improvements in mean donning time in the water resulting from the practice and equipment familiarization were due in part to elimination of the specific difficulties listed in Table I-42. Statistically significant improvements were seen in two test articles (WPI and WE3). These were among the nine articles with which statistically significant differences were found during donnings on land.

The specific difficulties which were experienced in the water were in some cases essentially the same as was experienced on land (e.g., WEI and WP3). Difficulty was experienced with WE3 in that the hood, which is held to the back of the suit by two simple snaps, separated from the suit and had to be retrieved to complete the donning. This difficulty could probably be eliminated by the use of "pull the dot" - type snaps to hold the hood to the suit.

In two donnings with WPI, the four snaps which secure the beaver tail in its deployed position were attached out of sequence giving incomplete closure of the jacket at the groin. This difficulty could possibly be eliminated by alternating male and female snap parts so that a misalignment by one snap in either direction (the most common mistake) would be impossible.

7.0 BUOYANCY INVESTIGATION

7.1 Objectives

The objective of the buoyancy investigation was to develop data describing the lift force which is intrinsic to each of the test articles considered in the study. By intrinsic lift it is meant that this lift does not depend upon any supplementation, by devices not integral to the test articles, or upon the integrity of any inflatable chambers. Thus all test articles which featured inflatable chambers were investigated for buoyancy with these chambers emptied to the maximum extent possible. This investigation included consideration of only the magnitude of the lift force intrinsic to each test article. No consideration was given to breathing passage freeboard, righting moment or flotation attitude, although the latter was illustrated by photographs in Chapter 2.

7.2 Methodology

The approach used to determine lift force was to measure first the weight (W_1) of each test article while enclosed submerged in a container with sufficient weights to make the aggregation negatively buoyant. Next the weight (W_2) of the container and weights submerged without the test article was measured. Of course, this latter weight was the greater of the two if the test article was positively buoyant. The arithmetic difference between the two weights ($W_2 - W_1$) was taken as the buoyancy of each test article.

The conditions under which the weights (W_2) of the test articles, container and weights were measured are as follows. Prior to loading each test article into the container, it was moved to different orientations in the water until all pockets of air trapped beneath it were released. When no further movement of the test article released trapped air, it was loaded into the weighted container and submerged under 2 inches of fresh water for 24 hours. The weight of the test article, container and weights was measured in that position.

A nylon mesh bag with a "purse-string" closure was used as the submerging container for the measurements. Weight measurements were made with a Chatillon spring scale (Model No. P/N DPPH-100).

7.3 Results

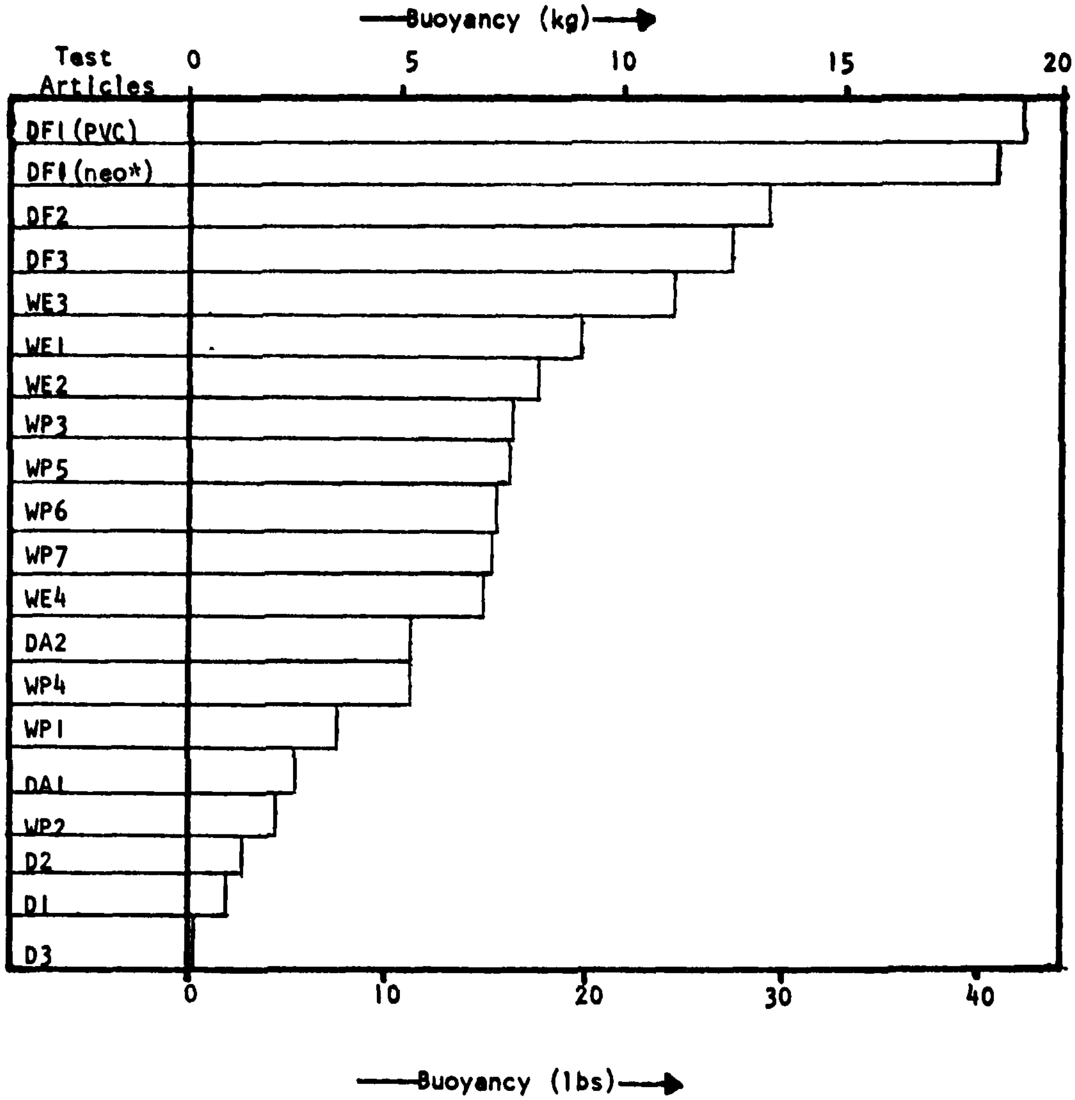
The intrinsic lift force determined for each of the test articles in fresh water is shown in Table I-43. These buoyancies are graphically illustrated in Figure I-8. The test articles have been ranked in order of decreasing buoyancy. The corresponding lift forces in sea water and would be expected to be about 3 percent greater.

7.4 Analysis and Discussion

The results of this investigation are straight forward and easy to interpret. However, a brief word of caution is in order for the results shown for DA1, DA2, WE1, WE3, DF3 and DF1 (PVC and neoprene). These test articles all have inflatable chambers of some size associated with them. Since it was desired that only intrinsic buoyancy be included in this investigation, the suits were all studied with their inflatable chambers emptied to the maximum extent achievable by physically compressing them. It is likely, however, that these chambers still contained some small amount of trapped air which would contribute to the lift forces indicated in Table I-43. The magnitude of this contribution is thought to be very small. Therefore, while the forces indicated for these test articles are upper bounds on their intrinsic buoyancy, they may also be regarded as reasonably accurate estimates of the buoyancies.

The test articles have arranged themselves, in Table I-43 and Figure I-8, in remarkably coherent groups. The most intrinsically buoyant articles are the DF suits followed closely by the WE's, then the WP's and finally the D's. The two DA-type suits are mixed among the WP's. The only other exception to this complete segregation of the test articles is the occurrence of WE4 among the WP's.

FIGURE 1-8
TEST ARTICLE BUOYANCY



* neoprene

TABLE I-43
BUOYANCY OF TEST ARTICLES

Code	Test Article Description	Size*	Fresh Water Lift Force (kg)
DF1 (PVC)	Bayley Exposure Suit (PVC)	X	19.1
DF1 (neoprene)	Bayley Exposure Suit (neoprene)	X	18.4
DF2	Helly-Hansen Survival Suit	M	13.3
DF3	S.I.D.E.P. Seastep Survival Suit	M	12.4
WE3	Stearns Heavy-Duty Offshore Survival Suit	M	11.1
WE1	Bayley WeatherMate Plus	M	9.0
WE2	Henderson Zip-On Exposure Suit	M	8.0
WP3	Mustang U-VIC Thermofloat	M	7.4
WP5	Stearns Windjammer Jacket	M	7.3
WP6	Stearns Offshore Survival Jacket	S/M	7.1
WP7	Texas Recreation Corp. Nylon-Covered PFD	M	6.8
WE4	White Stag Nylon-Two Wet Suit	M	6.7
DA2	Dr. S.B. Rentsch's Prototype Survival Suit	X	5.1
WP4	NADC Modified Wet Suit	MR	5.1
WP1	Henderson Prototype Jacket	M	3.3
DA1	ILC Industries Prototype Survival Suit	X	2.5
WP2	Medalist Ski Shorty	M	1.9
D2	NADC Goretex Experimental Coverall	38R	1.1
D1	Beaufort MK-10 British Immersion Coverall	68-71"	0.8
D3	U.S. Air Force Modified Anti-Exposure Assembly	M	0.1

* S = Small
M = Medium
S/M = Small/Medium
MR = Medium, Regular Length
38R = 38" Chest, Regular Length
68-71" = Height in Inches
X = One-Size-Fits-All or Unsized Prototype

8.0 AESTHETIC-APPEAL/WEARER-CONFIDENCE INVESTIGATION

It is obvious that hypothermia protection equipment which is not used is of no value. The different sectors of the overall population at risk addressed in this study may be expected to be more inclined to use some types of protection equipment than others. Recreational boaters who must purchase their equipment may be very conscious of its cost. Their use of it is also likely to be influenced by its looks (aesthetic appeal) and comfort as well as their perception of its cold-protection effectiveness (wearer confidence). Military crewmen and merchant mariners may be unconcerned with cost and aesthetic appeal. But their inclination to use a particular device will probably be much influenced by its comfort and their confidence in it. One might expect that the willingness to endure discomfort would be reinforced by strong feelings of confidence that the device would perform well if it was needed. Thus wearer confidence might be particularly important in devices intended for use in a constant-wear mode.

8.1 Objectives

The objectives of this investigation were to obtain evaluations of the intrinsicaesthetic-appeal of each of the test articles considered in this study and the wearer confidence engendered by them. It was desired that the aesthetic-appeal evaluation should be based upon physical examinations of the test articles and that it should not be influenced by overt presentation of information concerning non-obvious design features. It was desired that the wearer confidence evaluation be performed with the benefit of general information about the design features incorporated into each test article.

8.2 Methodology

These two evaluations were performed by specially-selected test subjects who had not participated in any other investigations in this study. They were selected to provide the broadest possible spectrum of backgrounds and interests. Relevant characteristics of these subjects, all of whom were college students, are presented in Table 1-44.

TABLE 1-44
DESCRIPTIONS OF
AESTHETIC-APPEAL/WEARER-CONFIDENCE INVESTIGATION SUBJECTS

	Subject	Age	Year	Major	Hobbies/Interests
Group 1	MC	21	Junior	Administrative Management	Golf, basketball, sports cars bottle collecting
	BD	20	Junior	Zoology	Photography, running
	EE	21	Junior	Accounting	Skydiving
	DL	20	Junior	Mechanical Engineering	Sports, reading
	BW	26	Senior	Forestry	Hunting, fishing, racquetball, tennis
Group 2	BB	29	Graduate Student	Zoology	Camping, hiking, fishing, SCUBA diving
	RB	23	Graduate Student	Bioengineering	Sailing, swimming, jogging snow skiing, hiking
	FC	20	Sophomore	Civil Engineering	Snow Skiing, swimming, sailing, racquetball, handball
	DD	20	Sophomore	Civil Engineering	Bowling, racquetball
	GS	31	Senior	Forestry	Tennis, reading, newspaper

These subjects were selected to participate in this investigation in two groups of five subjects each, as shown in Table I-44. This was done to keep to a reasonable size the group of individuals who had to inspect the test articles at any one time. In order to remove any bias which could result from model names or designations assigned by the manufacturers, the test articles were randomly assigned reference numbers which were used exclusively in referring to the articles and also in ordering their presentation to the subjects. Test Article DAI was evaluated by only the first group of subjects.

Aesthetic-Appeal Evaluation

For purposes of the aesthetic-appeal evaluation, the test articles were displayed to the subjects in the conditions in which they would normally be worn. All beaver tails and diapers were in the stowed position as were stowable hoods. All gussets were in the open position. The DA-type suits were shown in the deflated condition. No descriptions of the test articles were provided.

The instructions given prior to the aesthetic-appeal evaluation are shown in Figure I-9. The score sheet used is shown in Figure I-10. The five subjects were asked to start at one of the following reference numbers: 1, 4, 7, 10 and 13 and to progress through them in order of ascending reference numbers. At the conclusion of this evaluation the aesthetic-appeal score sheets were collected.

Wearer-Confidence Evaluation

For purposes of the wearer-confidence evaluation the test articles were displayed to the subjects in approximately the conditions in which they serve to protect the wearer against cold exposure. The beaver tails and diapers on jackets were not put into place since the suits were not being displayed on mannequins but rather were simply removed from their stowed position to call attention to their presence. The same is true of stowable hoods. All gussets were closed and the DA-type suits were fully inflated. The subjects were provided the general instructions shown in Figure I-11. They rated the test articles on the score sheet shown in Figure I-12. The subjects all began at the test article with reference number 1 and progressed in reference-number order reviewing the articles simultaneously. Audio-taped descriptions of the test articles were played while each was being considered. After each had been examined and scored, the taped descriptions were repeated

FIGURE I-9
AESTHETIC-APPEAL INSTRUCTION SHEET

Aesthetic-Appeal

Introduction

In this experiment you are asked to rate, on a scale of 0 to 10, the aesthetic appeal of several cold water protection suits. In other words, how well do you like the "looks" of these suits.

You may assume that the suits will be available in any color. Therefore, color should not be a factor in your ratings.

During this experiment you should not discuss the suits or the scores you have given them with anyone else.

Instructions

Each suit has been given a number. On the following page you will find a rating line corresponding to each suit number. Mark an "X" on the line to rate the suit. Also in the blank space on the right fill in the numerical equivalent of your rating. Fictitious suit number zero on the following page is shown as an example of the rating technique.

You will have ample time to look at each suit. You may pick the suits up to examine them. Take as much time as you need. You may come back and re-examine any suit. You may change the rating of a suit at any time.

FIGURE I-10
Rating Sheet for Aesthetic-Appeal

Suit No.	don't like					moderately like					like very much	Numerical score
0	0	1	2	3	4	5	6	7	8	9	10	4.9
1	0	1	2	3	4	5	6	7	8	9	10	
2	0	1	2	3	4	5	6	7	8	9	10	
3	0	1	2	3	4	5	6	7	8	9	10	
4	0	1	2	3	4	5	6	7	8	9	10	
5	0	1	2	3	4	5	6	7	8	9	10	
6	0	1	2	3	4	5	6	7	8	9	10	
7	0	1	2	3	4	5	6	7	8	9	10	
8	0	1	2	3	4	5	6	7	8	9	10	
9	0	1	2	3	4	5	6	7	8	9	10	
10	0	1	2	3	4	5	6	7	8	9	10	
11	0	1	2	3	4	5	6	7	8	9	10	
12	0	1	2	3	4	5	6	7	8	9	10	
13	0	1	2	3	4	5	6	7	8	9	10	
14	0	1	2	3	4	5	6	7	8	9	10	
15	0	1	2	3	4	5	6	7	8	9	10	
16	0	1	2	3	4	5	6	7	8	9	10	
17	0	1	2	3	4	5	6	7	8	9	10	
18	0	1	2	3	4	5	6	7	8	9	10	
19	0	1	2	3	4	5	6	7	8	9	10	
20	0	1	2	3	4	5	6	7	8	9	10	

FIGURE I-11
WEARER-CONFIDENCE INSTRUCTION SHEET

Wearer-Confidence

Introduction

In this experiment you are asked to rate, on a scale of zero to ten, your confidence in the ability of several suits to protect you against the effects of cold water (e.g. 35°F).

Basic Principles

The human body must maintain its core or central temperature within narrow limits for survival. If too much heat is removed from the body, its temperature will drop resulting in death. Insulating the body will decrease the amount of heat removed.

The thickness of an insulation layer and the type of material from which it is made will determine its insulating value. For any material the thicker the better. Stagnant (non-moving) air is the best insulating material available. The value of the fiberglass insulation used in homes is not in the fiberglass itself, but in the air trapped between the fibers.

Water is a poor insulater. Therefore, a "dry" suit may have advantages over a "wet" suit (one which allows water to come in contact with the body).

In "wet" suits, stagnant water, which will soon warm up, is to be preferred over the case where cold water can continually flush into or underneath the suit. Therefore, tight seals and snug fit are important design features for the "wet" suits.

The more body surface that is protected the better. It is especially important to keep the torso or trunk portion of the body covered in order to protect the internal organs such as the heart.

Instructions

The suits have been numbered. On the following page you will find a rating line corresponding to each suit number. Mark an "X" on the line to rate the suit. Also, in the blank space on the right of each line, fill in the numerical equivalent of your rating. Fictitious suit number zero is shown as an example of the rating technique.

The protective features of each suit will be read to you. You may go back to any suit and reread its protective features. You may change the score of any suit if you wish.

You may assume that additional flotation devices will be provided if the suit will not float you by itself. Those suits requiring extra flotation will be pointed out to you.

FIGURE I-12
Wearer-Confidence Rating Sheet

Suit No.	not confident					moderately confident					fully confident	Numerical Rating
0	0	1	2	3	4	5	6	7	8	9	10	5.2
1	0	1	2	3	4	5	6	7	8	9	10	
2	0	1	2	3	4	5	6	7	8	9	10	
3	0	1	2	3	4	5	6	7	8	9	10	
4	0	1	2	3	4	5	6	7	8	9	10	
5	0	1	2	3	4	5	6	7	8	9	10	
6	0	1	2	3	4	5	6	7	8	9	10	
7	0	1	2	3	4	5	6	7	8	9	10	
8	0	1	2	3	4	5	6	7	8	9	10	
9	0	1	2	3	4	5	6	7	8	9	10	
10	0	1	2	3	4	5	6	7	8	9	10	
11	0	1	2	3	4	5	6	7	8	9	10	
12	0	1	2	3	4	5	6	7	8	9	10	
13	0	1	2	3	4	5	6	7	8	9	10	
14	0	1	2	3	4	5	6	7	8	9	10	
15	0	1	2	3	4	5	6	7	8	9	10	
16	0	1	2	3	4	5	6	7	8	9	10	
17	0	1	2	3	4	5	6	7	8	9	10	
18	0	1	2	3	4	5	6	7	8	9	10	
19	0	1	2	3	4	5	6	7	8	9	10	
20	0	1	2	3	4	5	6	7	8	9	10	

while the subjects were allowed to freely inspect the articles. When each subject indicated that he was satisfied with his scores for the test articles, the score sheets were collected and the subjects were dismissed.

8.3 Results

The results of the aesthetic-appeal and wearer-confidence evaluations are presented, in terms of the mean score for each test article and the standard error of these means, in Tables I-45 and I-46, respectively. The test articles are ranked in these tables in order of decreasing mean scores.

8.4 Analysis and Discussion

It may be seen in Table I-45 that, on the basis of aesthetic-appeal, the test articles have been essentially dichotomized into wet-mode and dry-mode articles. A clear preference is shown for the wet-mode articles. The statistical significances of the differences among the aesthetic-appeal results obtained for the test articles are shown in Table I-47. This table shows the levels at which the aesthetic-appeal scores assigned the articles indicated by the rows are superior to the articles indicated by the columns. The only assumption invoked is that the random variation in the scores is normally distributed for each test article. An approximate t test has been used with Satterthwaite's approximation for degrees of freedom.

The mean wearer's confidence scores shown in Table I-46 agree reasonably well with the survival-time estimates given in Table I-14. The coefficient of correlation for these data (using the "closed" survival-time estimate for DA2) is 0.85. This indicates that people are capable of anticipating with reasonable accuracy the potential of various devices to provide protection during cold-water immersion. The statistical significances of the differences among the wearer-confidence scores are shown in Table I-48. These data are analogous to those shown in Table I-47.

TABLE I-45
AESTHETIC-APPEAL EVALUATION RESULTS

Test Article	SCORES Mean	S.E.M.
WE4 - White Stag Nylon-Two Wet Suit	8.13	.53
WE2 - Henderson Zip-On Exposure Suit	7.89	.37
WP7 - Texas Recreation Corp. Nylon-Covered PFD	7.86	.45
WP1 - Henderson Prototype Jacket	7.52	.37
WP2 - Medalist Ski Shorty	7.21	.61
WP5 - Stearns Windjammer Jacket	7.16	.28
WP6 - Stearns Offshore Survival Jacket	6.90	.40
WE1 - Bayley WeatherMate Plus	6.84	.59
WE3 - Stearns Heavy-Duty Offshore Survival Suit	6.65	.36
WP3 - Mustang U-VIC Thermofloat	6.47	.41
DF2 - Helly-Hansen Survival Suit	5.75	.62
DA1 - ILC Industries Prototype Survival Suit	5.74	.75
DF1 - Bayley Exposure Suit	4.53	.51
D2 - NADC Goretex Experimental Coverall	3.28	.53
DA2 - Dr. S. B. Rentsch's Prototype Survival Suit	2.85	.37
DF3 - S.I.D.E.P. Seastep Survival Suit	2.49	.77
WP4 - NADC Modified Wet Suit	2.40	.36
D3 - U.S. Air Force Modified Anti-Exposure Assembly	2.38	.36
D1 - Beaufort MK-10 British Immersion Coverall	2.14	.37

TABLE 1-46
WEARER-CONFIDENCE EVALUATION RESULTS

Test Article		SCORES Mean	S.E.M.
DA2	Dr. S.B. Rentsch's Prototype Survival Suit	9.08	.34
DA1	ILC Industries Prototype Survival Suit	8.82	.57
DF2	Helly-Hansen Survival Suit	8.53	.23
DF1	Bayley Exposure Suit	8.14	.31
DF3	S.I.D.E.P. Seastep Survival Suit	7.34	.46
WE2	Henderson Zip-On Exposure Suit	7.14	.49
WE3	Stearns Heavy-Duty Offshore Survival Suit	7.02	.41
WE4	White Stag Nylon-Two Wet Suit	6.84	.64
D2	NADC Goretex Experimental Coverall	6.19	.52
D1	Beaufort MK-10 British Immersion Coverall	6.18	.62
WE1	Bayley WeatherMate Plus	5.93	.61
D3	U.S. Air Force Modified Anti-Exposure Assembly	5.84	.53
WP6	Stearns Offshore Survival Jacket	4.49	.47
WP3	Mustang U-VIC Thermofloat	4.09	.47
WP1	Henderson Prototype Jacket	3.74	.54
WP2	Medalist Ski Shorty	3.69	.59
WP4	NADC Modified Wet Suit	3.35	.55
WP5	Stearns Windjammer Jacket	2.19	.41
WP7	Texas Recreation Corp. Nylon-Covered PFD	0.27	.08

TABLE 1-47
COMPARISONS AMONG AESTHETIC-APPEAL SCORES

Superior Test Article \ Inferior Test Article	WE4	WE2	WP7	WP1	WP2	WP5	WP6	WE1	WE3	WP3	DF2	DA1	DF1	D2	DA2	DF3	WP4	D3	D1
WE4	-	.36	.35	.18	.13	.06	.04	.06	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
WE2		-	.48	.24	.18	.07	.04	.08	.01	.01	.01	.02	.01	.01	.01	.01	.01	.01	.01
WP7			-	.28	.20	.10	.06	.09	.03	.02	.02	.02	.01	.01	.01	.01	.01	.01	.01
WP1				-	.34	.23	.14	.18	.06	.04	.01	.04	.01	.01	.01	.01	.01	.01	.01
WP2					-	.47	.34	.33	.22	.16	.05	.08	.01	.01	.01	.01	.01	.01	.01
WP5						-	.31	.32	.14	.09	.03	.07	.01	.01	.01	.01	.01	01	.01
WP6							-	.47	.32	.23	.07	.11	.01	.01	.01	.01	.01	.01	.01
WE1								-	.39	.31	.11	.14	.01	.01	.01	.01	.01	.01	.01
WE3									-	.37	.11	.16	.01	.01	.01	.01	.01	.01	.01
WP3										-	.17	.21	.01	.01	.01	.01	.01	.01	.01
DF2											-	.49	.25	.01	.01	.01	.01	.01	.01
DA1												-	.11	.01	.01	.01	.01	.01	.01
DF1													-	.05	.01	.02	.01	.01	.01
D2														-	.26	.21	.10	.09	.05
DA2															-	.35	.20	.19	.20
DF3																-	.46	.45	.34
WP4																	-	.48	.31
D3																		-	.32
D1																			-

TABLE 1-48
COMPARISONS AMONG WEARER-CONFIDENCE SCORES

Superior Test Article \ Inferior Test Article	DA2	DA1	DF2	DF1	DF3	WE2	WE3	WE4	D2	D1	WE1	D3	WP6	WP3	WP1	WP2	WP4	WP5	WP7
DA2	-	.35	.29	.03	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
DA1		-	.33	.16	.04	.03	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
DF2			-	.35	.27	.01	.01	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
DF1				-	.08	.05	.02	.05	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
DF3					-	.39	.31	.27	.06	.08	.04	.02	.01	.01	.01	.01	.01	.01	.01
WE2						-	.43	.36	.10	.12	.07	.04	.01	.01	.01	.01	.01	.01	.01
WE3							-	.42	.11	.14	.08	.05	.01	.01	.01	.01	.01	.01	.01
WE4								-	.22	.23	.16	.14	.01	.01	.01	.01	.01	.01	.01
D2									-	.50	.38	.32	.01	.01	.01	.01	.01	.01	.01
D1										-	.39	.34	.02	.01	.01	.01	.01	.01	.01
WE1											-	.46	.03	.01	.01	.01	.01	.01	.01
D3												-	.03	.01	.01	.01	.01	.01	.01
WP6													-	.33	.19	.19	.09	.01	.01
WP3														-	.32	.30	.16	.01	.01
WP1															-	.48	.31	.02	.01
WP2																-	.34	.03	.01
WP4																	-	.05	.01
WP5																		-	.01
WP7																			-

9.0 FIRE-RESISTANCE INVESTIGATION

The flame resistance of some hypothermia protection devices may be important. If a device is either flammable or easily degraded by exposure to flame, it should not be used in an environment which entails significant risk of fire. The potential for disaster is in no case more apparent than with the D-type articles. While their nomex undergarments are highly flame resistant, their cold-protection effectiveness is entirely dependent upon the integrity of their dry outer shell. If this integrity is easily deteriorated by flame exposure, then these devices should not be used where the risk of flame exposure is significant. Of course, the cold-protection effectiveness of foam rubber articles would be expected to be less easily deteriorated by flame exposure.

9.1 Objectives

The objective of this investigation was to assess, for a number of specially-selected articles, the susceptibility to damage by exposure to flame and any propensity to sustain burning oxidation after the flame exposure. The test articles to be considered in this investigation are indicated in Table 1-2.

9.2 Methodology

Two kinds of results are reported in this chapter. They include the results of flame-exposure tests conducted by Underwriters Laboratories at their Tampa, Florida Testing Station. These tests were conducted with whole garments in accordance with "Standard for Marine Buoyant Devices" (UL 1123). This standard specifies 2 seconds of exposure to the flame of a gasoline fire in a vertical position 229 mm (9 inches) above the shallow container holding the gasoline. The flame is produced by 25.4 to 50.8 mm (1 to 2 inches) of gasoline, floating on 12.7 mm (1/2 inch) of water in a 305 by 457 by 63.5 mm (12 by 18 by 2.5 inch) metal pan which ahs been burning freely for 30 seconds. The results of UL flame-exposure tests are included for WP3, WP5, WP6 and DF1(neoprene). Following flame exposures, the three WP-type devices were tested for tensile strength at a tension reduced to 102.3 kg (75 percent of the normal test value). The tensile testing procedure described in UL 1123 was employed for this test. These results were released by UL, for inclusion

in this report, after receiving the authorization of the respective manufacturers.

Test article WE3 is of very similar construction to WP5 and WP6 regarding fire resistance. It would probably normally be covered by an outer envelope of 200 denier fabric as were WP5 and WP6. This would render the same fire resistance results seen for them easily achievable in WE3.

Seven of the test articles considered in this investigation are constructed of neoprene rubber. They are DF1(neoprene), WE1, WE2, WE4, WP1, WP2 and WP4. It will be assumed that the intrinsic fire resistance of neoprene rubber would produce with each of these articles flame-exposure results similar to those described in this chapter for DF1(neoprene) and WP1. Test article WP1 employs two exposed plastic zippers on the torso which would be subject to considerable weakening during flame exposure. They are the primary closure and the torso gusset, both of which must function for the article to provide significant protection in cold water. Article WP1 was tested using generally the flame exposure protocol described in UL 1123. The following deviations were made. The metal pan was 40.6 by 43.2 cm (16 by 17 inches), the water and gasoline layers were 1.9 cm (0.75 inches) deep, and the pre-and post-flame-exposure tensile strength tests were done using cylinders 11.4 cm (4.5 inches) in diameter.

The remaining test articles (D1, D2, D3 and DA1) are addressed by flame exposure testing swatches of goretex and ventile fabrics. Three laminated composite fabrics including goretex were tested. Each of the composite fabrics is composed of three layers, with the middle one being goretex. One composite included an outer layer of nomex twill and an inner layer of nylon tricot. This is the material of which article D2 is constructed. The second had an outer layer of nomex type 456 (plain weave, 4.7 oz/yd^2) and an inner layer of nomex jersey knit (1.5 oz/yd^2). The third had an outer layer of nomex (plain weave, 1.9 oz/yd^2) and the same inner layer as the second composite. The swatch of woven ventile cotton fabric had stretch inserts of polychloroprene coated nylon. It is generally similar to the material from which D1 and D3 were constructed.

The protocol for testing the swatches is as follows. Each swatch was draped over the open top of a circular steel container 216 mm in diameter.

The outside of the swatch was on top. A depression was made in the swatch and it was secured to the edges of the container by spring clips. Two hundred and thirty-seven milliliters (8 fluid ounces) of water was placed in the depression. It arranged itself in a roughly circular shape, approximately 133 mm in diameter, with a maximum depth of 25 mm in the center. It was allowed to stand for two hours and the volume of water passing through the fabric was measured. This procedure was repeated after exposing the fabric swatches to flames to determine if any deterioration in their water repellent properties had occurred. It was desired that the flame exposure be restricted to impinge directly only on the outside of the fabric as it would if someone wearing coveralls constructed of the materials was exposed to flames before entering the water. To accomplish this, rectangular swatches 30 by 40 cm were folded in half to dimensions 30 by 20 cm (with the inside surface toward the inside of the fold) and sealed around the three open edges by a 2-piece, U-shaped wooden frame held together by C-clamps. This protected the inside surface of the material from direct exposure to the flames. The usual 2-second exposure to gasoline flames at a height of 22.8 cm (9 inches) was used. The gasoline was floating on 1.9 cm (0.75 inches) of water and had been burning for 30 seconds before a swatch was inserted.

9.3 Results

WP3 - Mustang U-VIC Thermofloat (200-denier, fabric outer envelope)

The results of the UL flame exposure test with WP3(UL reference: File MQ269, page TI-11, issued 5-19-77) are stated as follows:

"No failure. Slight discoloration due to smoke."

WP5 - Stearns Windjammer Jacket (70-denier,fabric outer envelope)

The results of the UL flame exposure test with WP5 (UL reference: File MQ 29, page TI-4, issued 12-14-72) are stated as follows:

"No failures of any kind."

WP6 - Stearns Offshore Survival Jacket (200-denier, fabric outer envelope)

The results of the UL flame exposure test with WP6 (UL reference: File

MQ 29, Vol. 1, Sec. 14, page T1-8, Issued 11-3-77) are stated as follows.

"No failure. Slight discoloration due to smoke."

DFI (neoprene - Bayley Exposure Suit

The results of the UL flame-exposure test with DFI (neoprene) (UL reference: unknown) are stated as follows.

> "Only light scorching on the legs and foot resulted from the test. Since the damage was only minimal, no follow-up testing was conducted."

WPI - Henderson Prototype Jacket

The flame exposure testing with WPI produced only slight scorching of the material. Tensile strength tests conducted with 136.4 kg (300 lbs.) before flame exposure and 102.3 kg (225 lbs.) after flame exposures produced no failures of any kind. The performance of the article would not be impaired by 2-second exposures to gasoline flames.

It should be noted that Stoll, et al., (1976) reported severe damage to nylon-faced neoprene wet suits exposed to a somewhat more stressful test condition. Their protocol involved a 3-second exposure to fully-enveloping flames of burning aviation gasoline. Their results included melting of the nylon facing, adhesions of the neoprene and self-sustaining combustion of the neoprene (possibly supported by combustion of the adhesive material used to bond the nylon facing to the neoprene). The flame resistance of neoprene appears to be very dependent upon the specific nature of its flame exposure.

Nomex Twill/Goretex/Nylon Tricot Swatch

In the test of water tightness before the flame exposure, no water was seen to pass through the swatch in 2 hours of hydrostatic loading. After the 2-second flame exposure, the swatch was observed to be puckered on the nomex side but not on the nylon-tricot side. The nomex layer appeared to have separated from the goretex/nylon tricot layers. The condition of the goretex layer, between these two, could not be observed directly. It was separately determined that when a sample of goretex is exposed to the flame of a paper match at a distance of approximately 2 cm it contracts very

rapidly into a more dense aggregation of material which resists being stretched back to its original shape. When the swatch was again tested for its integrity as a water barrier, several small droplets of water formed in the receptacle under the swatch. However, the volume of water was too small to measure directly. This suggests that there had been some deterioration in the capability of the goretex to resist passage of water. Quantitating this observation is made difficult by the propensity of the water to "wick" slowly through the nomex twill outer layer and to drip from the material. Another serious concern raised by the puckering observed is that if the goretex layer of a survival suit were to shrink significantly, subsequent movement by the wearer could tear the goretex without damaging the other fabric components and create a massive leak in the water barrier. This could catastrophically degrade the immersion hypothermia protection provided by the survival suit.

Nomex (4.7 oz/yd^2)/Goretex/Nomex Jersey Swatch

In the test of water tightness before the flame exposure, no water was seen to pass through the swatch in 2 hours of testing. The heavy nomex plain weave outer layer was seen to "wick" as the nomex twill outer layer had. After the 2-second flame exposure, the swatch was observed to be puckered on both sides. This indicates that shrinkage of the goretex had occurred and was sufficiently pronounced to produce this puckering. The jersey knit layer could be seen to have separated from the goretex in the vicinity of the puckers. Puckering primarily occurred in the area of the material positioned closest to the flame. Some discoloration (from white to beige) occurred on the jersey knit side (inside) of the swatch. When the swatch was tested for its water tightness after the flame exposure, no water was seen to pass through the material.

Nomex (1.9 oz/yd^2)/Goretex/Nomex Jersey Swatch

In the test of water tightness before the flame exposure, no water was seen to pass through the swatch in 2 hours of testing. The light nomex plain weave outer layer was seen not to "wick" as the other outer layers had. After the 2-second flame exposure, the swatch was observed to be puckered on both sides. The puckered area was approximately three to four times the size of that seen with the 4.7 oz/yd^2 plain weave outer layer. The jersey knit was

separated from the goretex to a larger extent and the discoloration visible on the inside of the fabric was more profound (to a darker beige). When the swatch was again tested for its integrity as a water barrier, no water was seen to pass through the material.

<u>Ventile Cotton/Stretch Polychloroprene Swatch</u>

The water-tightness test before flame exposure resulted in no water passage through the swatch during the 2-hour hydrostatic loading. No tendency was observed for the water to "wick" through the material or even to penetrate the surface. It should be noted that this swatch (obtained from NADC) appeared to differ from the fabric used in the construction of D3 (the CWU-21/AP) which was obtained from the U. S. Air Force. After the flame exposure, no physical change in either the ventile or polychloroprene portions of the swatch could be detected. The repeat of the water tightness test resulted in the finding that no water had penetrated the fabric.

10.0 RELIABILITY INVESTIGATION

When any physical system is employed to perform a specified function there is always some chance that the system will not be in "working order" when it is called upon. The reliability of a system is generally taken to be the likelihood that it will be in working order when it is needed. The failure of a system may result from many separate causes, including defects in material or workmanship, improper preventive maintenance, and underrating the system for the stresses of its operational environment. The propensity of physical systems to fail is generally assessed through life-testing a large number of them, perhaps at elevated levels of stress. This type of test-bed evaluation is not the subject of this chapter.

10.1 Objectives and Methodology

The objective of this investigation was to gather and report specific observations of the occurrences of failures during the testing of the articles considered in this study. These observations indicate the number and type of equipment failures which could be expected at levels of stress comparable to those encountered in the other investigations in this study. To the extent that these stresses emulate a candidate operational environment, the results of this investigation may be interpreted as a limited test of operational reliability.

10.2 Results

The results of this investigation include identifications of all failures observed with all test articles included in the study. This includes some failures which are not critical to the performance of the test articles in prolonging survival but which may indicate maintenance nuisances if some design or manufacturing improvements are not made.

WE1 - Bayley WeatherMate Plus

Failures were observed in the adhesive holding patches of velcro hooks inside the jacket. These patches serve to hold the diaper in its stowed position.

WE3 - Stearns Heavy-Duty Offshore Survival Suit

The failure of the snaps, holding the hood to this survival suit, to meet the stresses imposed upon them during donning exercises in the water has previously been discussed in Section 6.4. An additional failure which occurred

during a donning exercise in the water was the breaking of the zipper which serves as the primary closure of the suit.

D2 - NADC Goretex Experimental Coverall

A failure of the elastic neck seal was observed during a donning exercise on land. The failure was in the form of a tear about 4 cm long beginning at the neck orifice. The effect of this failure would have been, at worst, a partial loss of the integrity of the neck seal.

D3 - U. S. Air Force Modified Anti-Exposure Assembly

Failures of the elastic stockings, integral to this suit, in the form of tears occurred during the fatigue-induction investigation. This type of failure completely defeats the dry aspect of the design of this suit. It is possible that the canvas sneakers with which this suit was tested imposed stresses upon the stockings, during the two-step protocol, which far exceed that which they are designed to endure.

DF1 (PVC) - Bayley Exposure Suit

A leak developed around the seam of the flotation "pillow" which attaches to this suit. The only consequence of this failure was the necessity for periodic reinflation of the pillow to maintain a constant flotation attitude.

DF2- Helly-Hansen Survival Suit

A minor failure occurred in one of the neoprene rubber wrist seals on this suit. The failure was in the form of a tear approximately 2 cm in length. The tear did not penetrate the nylon facing of the neoprene rubber. The wrist seal exhibited the strength to resist significant enlargement of the tear through several uses of the suit in cold-water immersions and fatigue-induction experiments which were performed after the tear initially formed. The effect of this material failure was no loss of suit performance.

DA2 - Dr. S. B. Rentsch's Prototype Survival Suit

Three of the circular patches, sealing the outer and inner layers of the primary air bladder together, separated. This results in a proportional loss of control of air space thickness and presumably some deterioration in the total rate of heat loss due to an increase in the convection component.

11.0 SUMMARY

A procedure for analyzing cold-immersion test data has been applied which allows estimation of cooling behavior for individuals with selected physical structures. This enabled the development of comparable survival-time estimates for a spectrum of articles tested by different groups of subjects. The procedure was applied to estimate survival times for thin, average and heavy individuals wearing the test articles in 1.7°C (35°F) water. This estimation involved the use of a mathematical thermal model of a protected man in a cold environment to account for the fact that not all of the articles could be tested in 1.7°C water.

These survival-time estimates revealed the general superiority of dry, insulated survival suits in preserving life. Among these suits, those employing inflatable air bladders as insulating media performed variably well. The effectiveness of respiratory heat reclamation has been clearly established. An increase in survival time of approximately 10 hours has been indicated in Dr. Rentsch's prototype due to respiratory heat reclamation. Efforts to effectively integrate this life-sustaining feature into practical survival-suit configurations should begin immediately.

The data which is most relevant to the problem of selecting equipment for various uses is summarized in Table 1-49. The test articles are ranked in order of decreasing estimated survival time for an average individual. This is regarded as the primary decision criterion. Test articles not included in the cold-immersion investigation are listed at the bottom of Table 1-49 to facilitate comparisons involving their results from other investigations. The survival times estimated for thin individuals are also included in Table 1-49 so that any desired minimum times may be assured for them as well. Next, the mean mobility reductions per subject have been summed over the elementary movements and are shown for each test article. This index is obviously insensitive to the relative importances of the various elementary movements to an intended, constant-wear use. The distributions of these totals across the elementary movements may be seen in Table 1-19. The requirements for the wearer to exert extra effort to perform the elementary movements are indicated for each article in Table 1-49 by the total number of subjective scores of 1 (indicates that full range of motion could be achieved but extra effort was required), summed over all elementary movements

TABLE I-49
SUMMARY OF RESULTS

Test Articles	Survival Times (hrs) Average	Survival Times (hrs) Thin	Total Mean Mobility Reductions(°)*	No. of Subjective Scores of 1 Per Subject ††	Mean Percent Increase in Heart Rate +	Mean Increase in Surface Temperature + (°C)	Mean Donning Time(min) @	Inherent Buoyancy (kg)	Aesthetic Appeal **	Wearer Confidence **
DA2(closed)	27.1	30.2	-	-	-	-	-	5.1	2.8	9.1
DA1	24.6	21.2	18	3.8	11.5	1.8	2.7	2.5	5.7	8.8
DF1 (PVC)	22.0	17.0	-	-	-	-	1.2	19.1	4.5	8.1
DF3	21.7	11.4	-	-	-	-	1.1	12.4	2.5	7.3
DF2	20.2	12.6	3	3.0	19.1	2.7	1.3	13.3	5.8	8.5
WE2	12.2	7.4	11	4.4	12.2	2.1	2.6	8.0	7.9	7.1
D2	9.8	6.1	57	4.5	6.8	0.8	1.5	1.1	3.3	6.2
WE3	9.1	9.5	6	3.0	4.2	2.1	0.8	11.1	6.6	7.0
WP2	8.9	7.0	28	3.0	4.0	1.4	0.8	1.9	7.2	3.7
WE1	7.7	5.2	20	3.4	9.8	2.4	1.9	9.0	6.8	5.9
WP6	6.9	4.0	0	1.0	1.7	1.5	1.0	7.1	6.9	4.5
D3	5.9	2.6	0	0.0	3.2	0.8	1.4	0.1	2.4	5.8
WP1	4.5	2.2	0	3.2	12.8	1.4	1.3	3.3	7.5	3.7
WP3	4.1	2.0	0	0.6	3.6	1.2	1.8	7.4	6.5	4.1
WP5	3.4	1.6	0	0.8	0.9	1.0	-	7.3	7.2	2.2
WP7	2.8	1.3	-	-	-	-	-	6.8	7.9	0.3
DF1(neo)	-	-	-	-	-	-	0.9	18.4	-	-
D1	-	-	0	2.0	8.5	1.2	1.3	0.8	2.1	6.2
WP4	-	-	41	5.6	5.3	2.0	1.6	5.1	2.4	3.4
WE4	-	-	10	5.8	8.9	2.6	3.8	6.7	8.1	6.8
								Averages	5.48	5.72

* Totaled for elementary movements, averaged per subject
\+ Activity Model I
@ On land, with practice
** Means of subjective scores on scale of 0 to 10 (increasing appeal and confidence)
†† Scores of 1 refer to need for extra effort to achieve full range of motion

and test subjects, divided by the number of subjects testing each article. These indices are an indication of how much a wearer might be fatigued in the process of overcoming article resistance to achieve full range of motion. The next data is also related to increases in fatigue induction. They are the mean percent increases in heart rate averaged over the test subjects (uniformly) and the three experimental exercises (in accordance with activity model 1). The tendencies of the articles to produce overheating have been expressed by mean increasès in skin surface temperature averaged uniformly over the test subjects and experimental exercises but using weighted averages of the three skin surface sites. Also, the mean times for donnings with practice on land are shown, as are the measurements of intrinsic buoyancy. Finally, the mean scores assigned in the subjective assessments of aesthetic appeal and wearer confidence are listed.

Table 1-49 shows survival-time superiority for the two test articles involving inflatable air-bladder insulation media. Of course DA2(closed) also has the benefit of respiratory heat reclamation. Test article DA2 was judged not to be a candidate for use in a constant-wear mode. Therefore, it was not included in the tests for constant-wear suitability. Since DA1 was configured as a flight garment, it was included in the investigations for constant-wear suitability. These revealed the 5th-largest reduction in mobility, the 5th-largest requirement for extra effort to achieve full range of motion, the 4th-largest increase in heart rate, and the 7th-largest increase in skin temperature. Its 2.7-minute, mean donning time is the 2nd-longest observed on land, but could probably be significantly reduced by replacing the primary, water-tight closure with a zipper. Its intrinsic buoyancy (2.5 kg) is among the smallest measured, but this was to be expected with an air-bladder suit. It received an aesthetic-appeal score slightly above mid-scale but the 2nd-largest wearer-confidence score.

By comparison, DF2 exhibits a very small reduction in mobility, but also the largest increases in heart rate and skin temperature. Its mean donning time of 1.3 minutes is generally acceptable for most purposes, as is its 13.3 kg intrinsic buoyancy. It received aesthetic-appeal and wearer-confidence scores almost identical to DA1.

A major decrease in survival time occurs when moving to the next article in Table 1-49 (WE2). The estimate for an average individual drops by 8 hours. The article affords no real improvement in wearability as indicated

by the mobility, heart rate and skin temperature data. When compared to the standard wet suit (WE4) it may be seen to afford reductions in the extra effort required to achieve full mobility and in the elevations in skin temperature it induces. However, an increase in heart rate elevations may also be seen with WE2. Its donning time is relatively long, but its intrinsic buoyancy is adequate and its aesthetic-appeal and wearer-confidence scores are relatively high.

Test article D2 offers some improvement in general wearability. It exhibited the smallest elevation in skin temperatures, but appears to severely restrict mobility. In reality this restriction is due to the "slim" tailoring of the prototype included in this study, see Figure 1-1(m). A more generous use of material in constructing the article, as was done with D3, Figure 1-1(n), would probably eliminate this problem. A more serious concern with D2 is its fire resistance. Based on the test described in Chapter 9, it appears that the goretex may be adversely affected by flame exposure resulting in degradation of its water resistance property. This finding indicates that goretex-based dry suits should be not used in an environment posing serious risk of flame exposure in conjunction with cold-water immersion, until more extensive testing is conducted. The intrinsic buoyancy of the dry coverall is very low as one would expect indicating the need for supplemental flotation. The D2 coverall was scored very low in aesthetic appeal but above average in wearer-confidence.

The next test article, WE3, offers 9 hours of survival-time to an average individual. While its wearability is not outstanding it may be seen to offer considerable improvement over a standard wet suit (WE4). The most important improvements are in the extra effort required to achieve full mobility and the heart-rate elevations it induces. It provides a small improvement in the elevations of skin temperatures.

It has been shown that a wet-mode suit covering only part of the body (WP2) can provide an average individual nearly 9 hours of survival time when used in conjunction with a "water-wings" PFD. However, it entailed relatively large mobility reductions and it required non-trivial extra effort to achieve full ranges of motion in some movements. Its 4 percent elevation in heart rate ranks 5th (from top of Table 1-49) and its 1.4°C increase in surface temperature ranks 6th.

Another such article (WP6) provides nearly 7 hours of survival time for an average individual and 4 hours for a thin one. It imposes no reductions in mobility and requires only a little extra effort to achieve full range of motion. Its 1.7 percent increase in heart rate ranks 2nd. However, its 1.5°C increase in surface temperature ranks only 8th.

Test article D3 was observed to provide an unreliable water barrier during the cold-immersion'experiments. Even so, it provides nearly 6 hours of survival time for average individuals and excellent wearability. However, it provides only 2.6 hours of survival time for thin individuals. This is 56 percent less than for average individuals, closely resembling the 53 percent difference seen in the minimally-protective WP7.

Test article WP1 provides about 4.5 hours of survival time for an average individual but only 2.2 hours for a thin one. It imposes no reductions in mobility but significant extra effort is required to achieve full ranges of motion. This is consistent with its 12.8 percent increase in heart rate which ranks 14th.

Test article WP3 affords 4 hours of survival time for an average individual and 2 hours for a thin one. On balance it appears to be one of the more wearable of the test articles. It possesses adequate intrinsic mobility and was scored well above average in aesthetic appeal.

The purpose of including the PFD (WP7) was to determine if there is a survival advantage afforded by the vest-thpe device which fits the torso snugly. In Table 1-10 a cooling rate of 1.46°C/hr was shown for an average individual in 11.8°C water. A survival-time estimate of 5.5 hours was developed for this morphology and water temperature. Hayward, et al., (1978) showed a mean cooling rate of approximately 2.32°C/hr., for a comparable group of individuals wearing kapok, keyhole-type PFD's in 11.8°C water. Using the survival-time formulation developed in Chapter 3 an estimate of 3.5 hours results for the kapok PFD. Therefore, an extension of 2 hours in survival-time is estimated to result with the vest-type PFD in 11.8°C water. This corresponds to a 57 percent extension and must be judged to be significant indeed.

It is important to recapitulate the conditions in which the cold-immersion

experiments were performed and, therefore, those in which the survival-time estimates would apply.

1. The positions of the subjects in the water were those resulting from flotation characteristics of the test articles with supplemental flotation as described in Chapter 2.

2. The water velocity was maintained at a level (3-5 m/min) which would effectively maximize convective heat loss,

3. No wave action was simulated; hence minimal hydrodynamic force was present to encourage flushing of cold water underneath the wet-mode test articles. Therefore, the survival-time estimates developed in this study for wet-mode articles are longer than those which may be expected in turbulent open water.

A number of specific objectives related indirectly to the equipment-selection problem have been addressed through ancillary studies. The results of these studies have been discussed in the preceding chapters but are not summarized in Table 1-49. These studies address the following points.

1. The propensity of the test articles to induce fatigue and overheating for various models of activity. General insensitivity to the specific nature of the activity was found.

2. The ease with which each test article may be donned in water.

3. The reductions in donning times (on land and in water) resulting from equipment familiarization and recent donning practice.

4. The identification of specific problems in donnings which may be reduced or eliminated through equipment modifications.

5. The identification of a potentially significant impact upon the performance of DF3 which results from improper donning.

6. The identification of reliability problems which could effect equipment performance and/or maintenance requirements.

It is not possible to prescribe the best equipment choice for all possible

users because of lack of information concerning the fine structure of their priority system. However, a basis for rational selections has been developed and described in this report. It is hoped that this information will be used to make informed decisions which will reduce the loss of life due to accidental cold-water immersion.

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APPENDIX A

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Attn: Mr. Dan Grohlke

ILC Dover Division
P. O. Box 266
Harrington Road
Frederica, DElaware 19946
Attn: Mr. Jack Rayfield

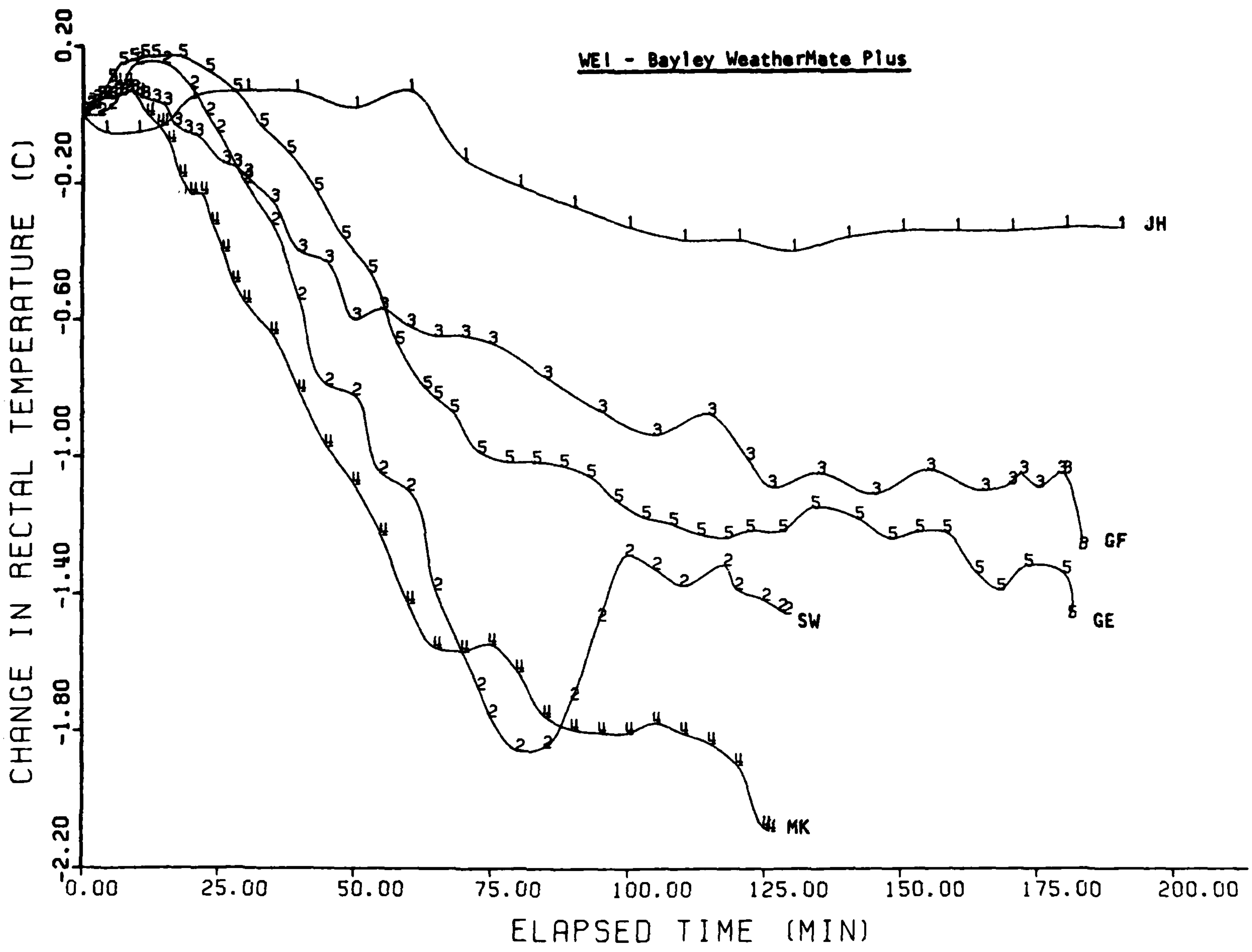
Life Support SPO (ASD/AELS)
Wright-Patterson AFB, Ohio 45433
Attn: Lt. Col. Weekly

Dive N Surf
504 Broadway
Redondo Beach, CA
90254
Attn: Ms. Sue Wilson

Diving Unlimited
International
1148 Delevan Drive
San Diego, CA
92102
Attn: Mr. Richard W.
Long

APPENDIX B

COOLING TEMPERATURE PROFILES



WEI - Bayley WeatherMate Plus
CHANGE IN RECTAL TEMPERATURE (C)
ELAPSED TIME (MIN)
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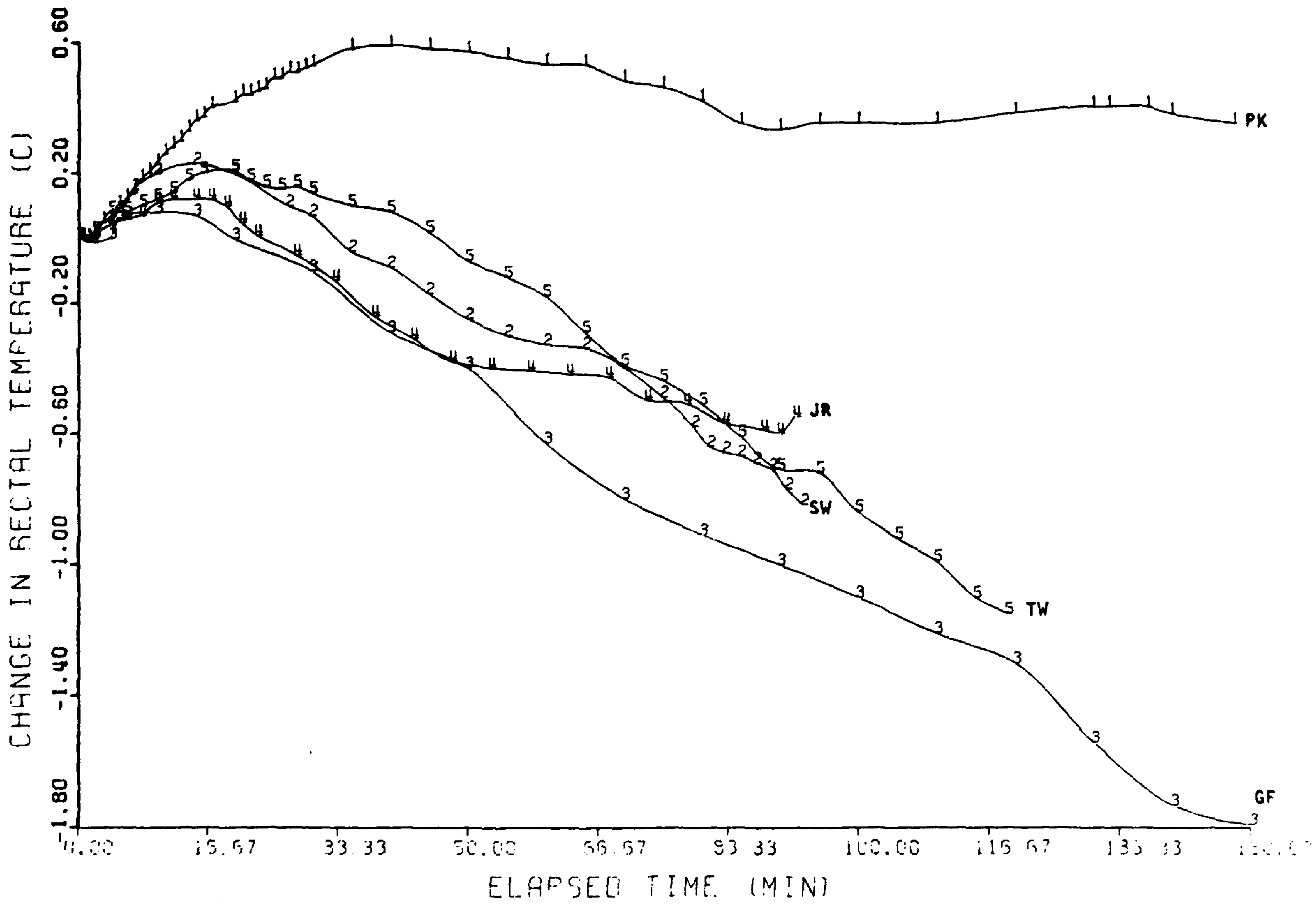
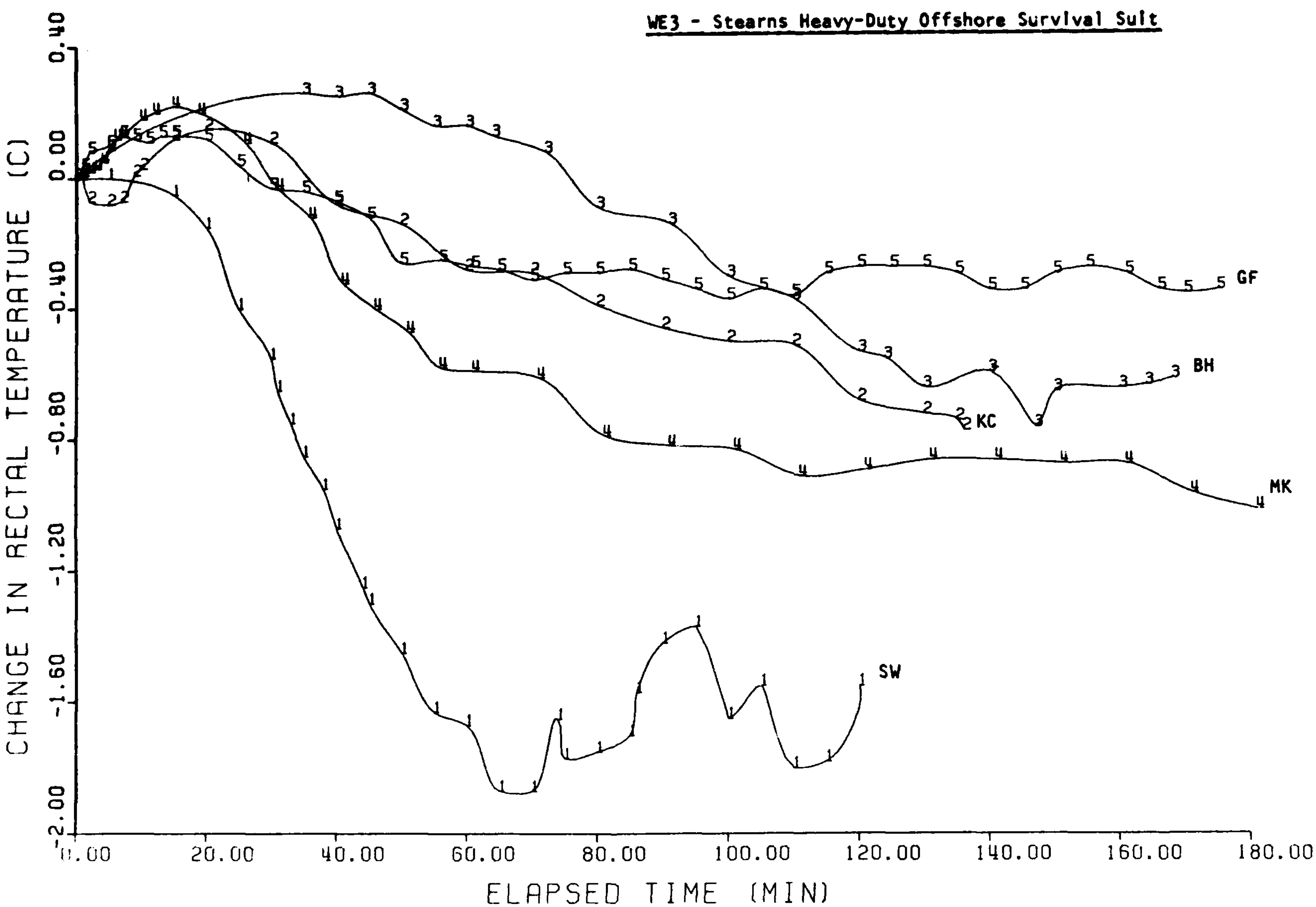
-0.20
-0.60
-1.00
-1.40
-1.80
-2.20
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
JH
GF
GE
SW
MK

WE2 - Henderson Zip-On Exposure Suit




WE3 - Stearns Heavy-Duty Offshore Survival Suit
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ELAPSED TIME (MIN)
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-1.20
-1.60
-2.00
0.00
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100.00
120.00
140.00
160.00
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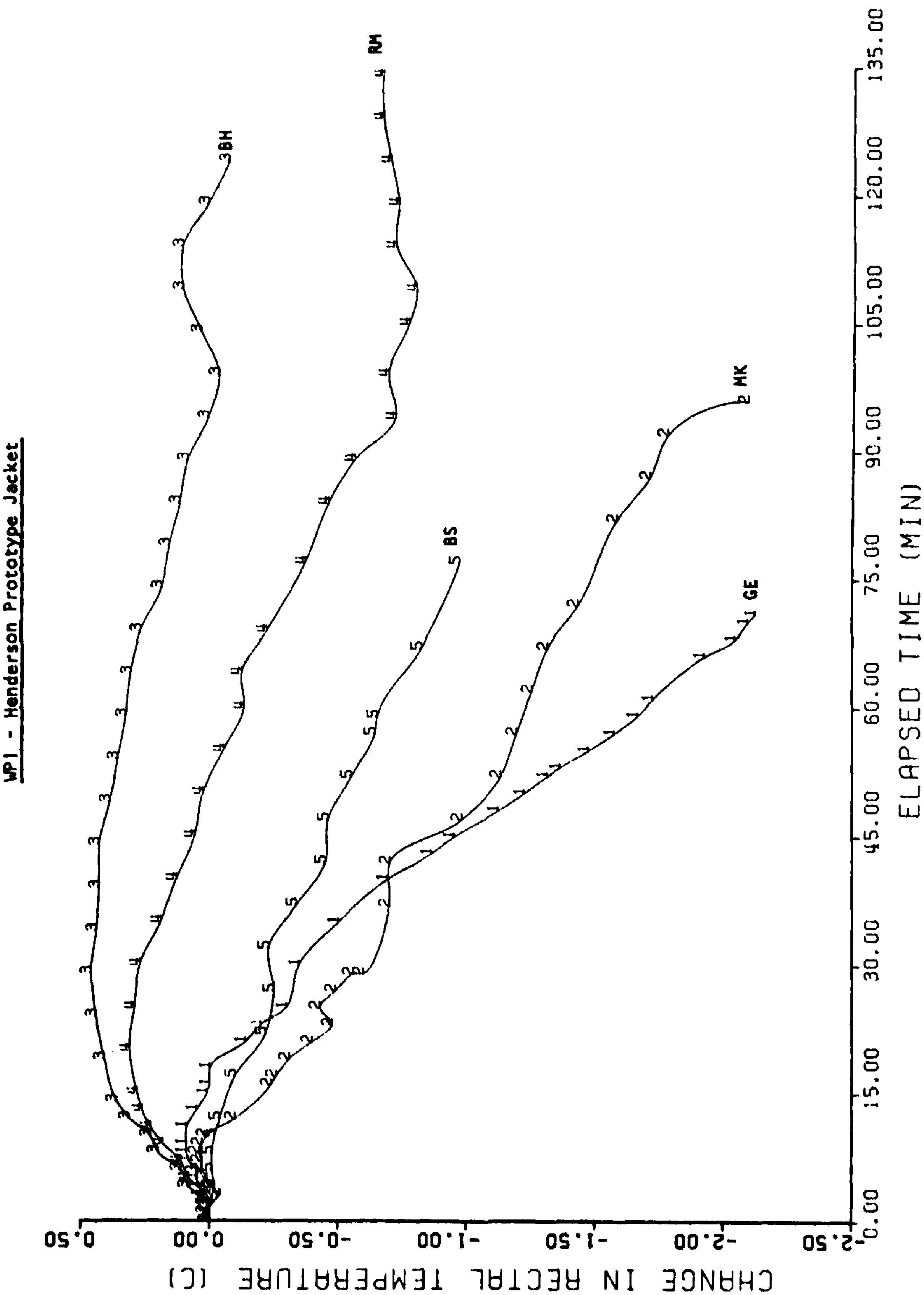
GF
BH
KC
MK
SW


WPI - Henderson Prototype Jacket
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-1.50
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-2.50
ELAPSED TIME (MIN)
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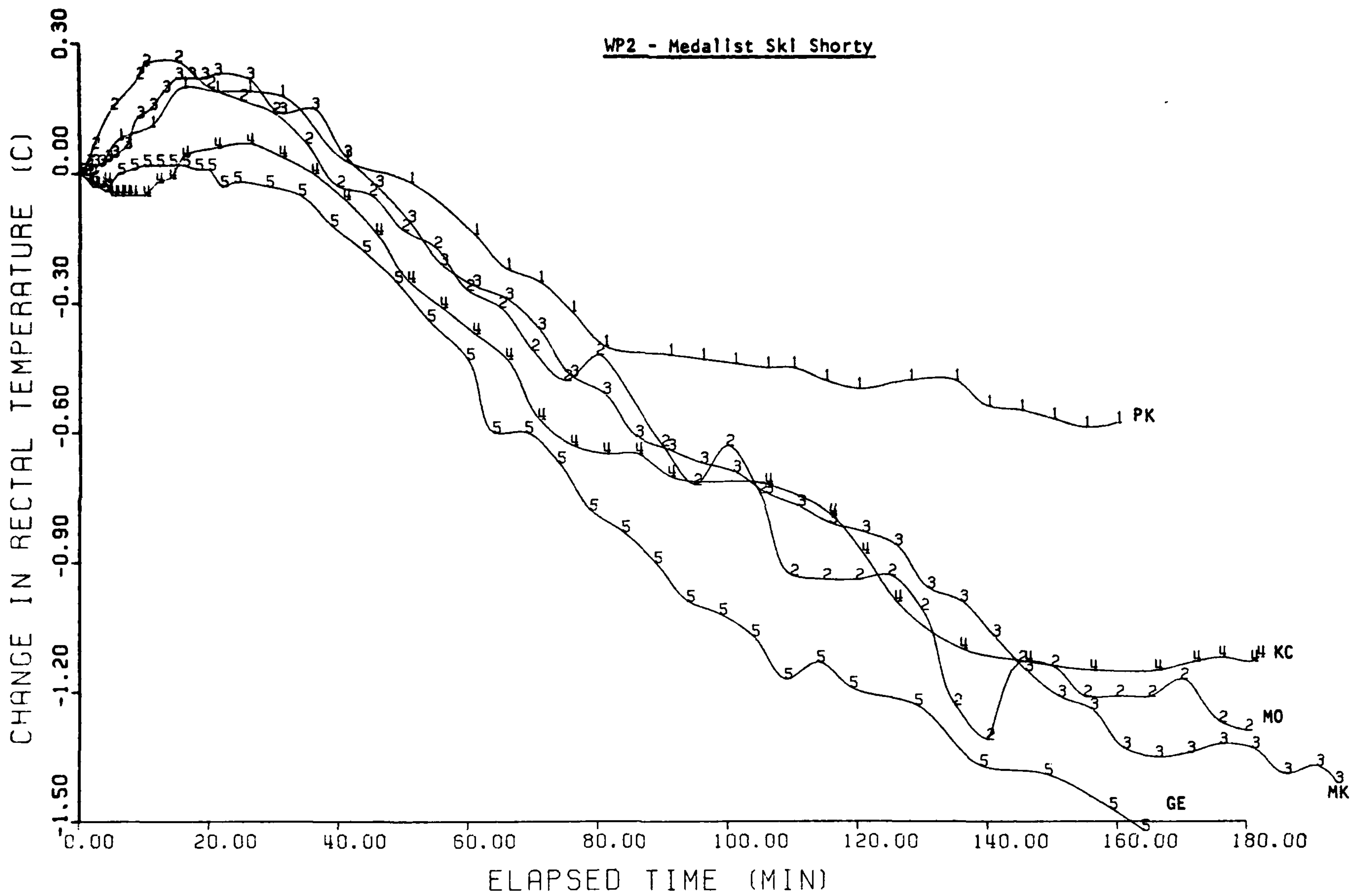
120.00
135.00
3BH
RM
BS
MK
GE


WP2 - Medalist Ski Shorty
CHANGE IN RECTAL TEMPERATURE (C)
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0.00
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60.00
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100.00
120.00
140.00
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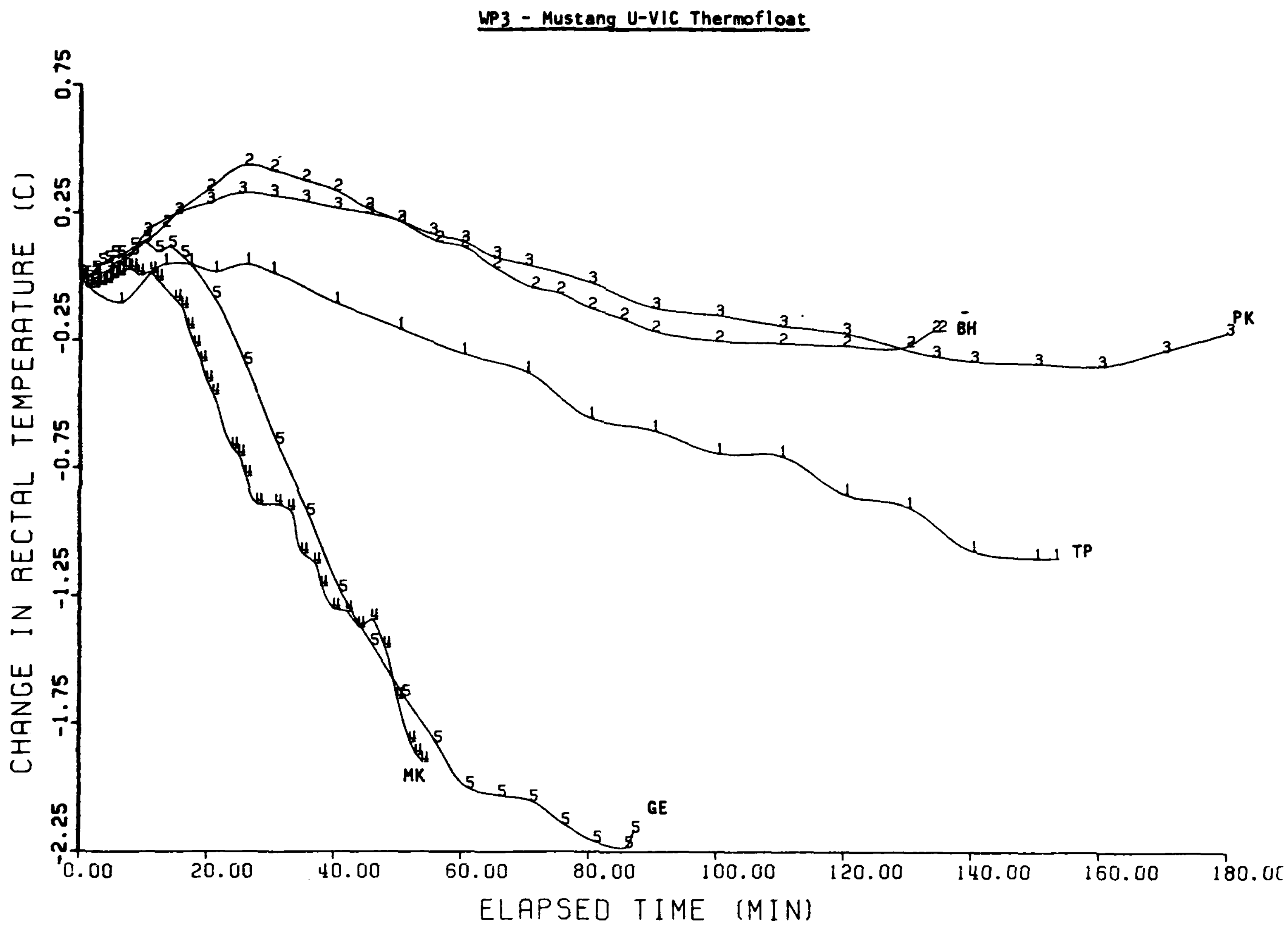
180.00
ELAPSED TIME (MIN)
PK
KC
MO
MK
GE



WP3 - Mustang U-VIC Thermofloat
CHANGE IN RECTAL TEMPERATURE (C)
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-1.75
-2.25
ELAPSED TIME (MIN)
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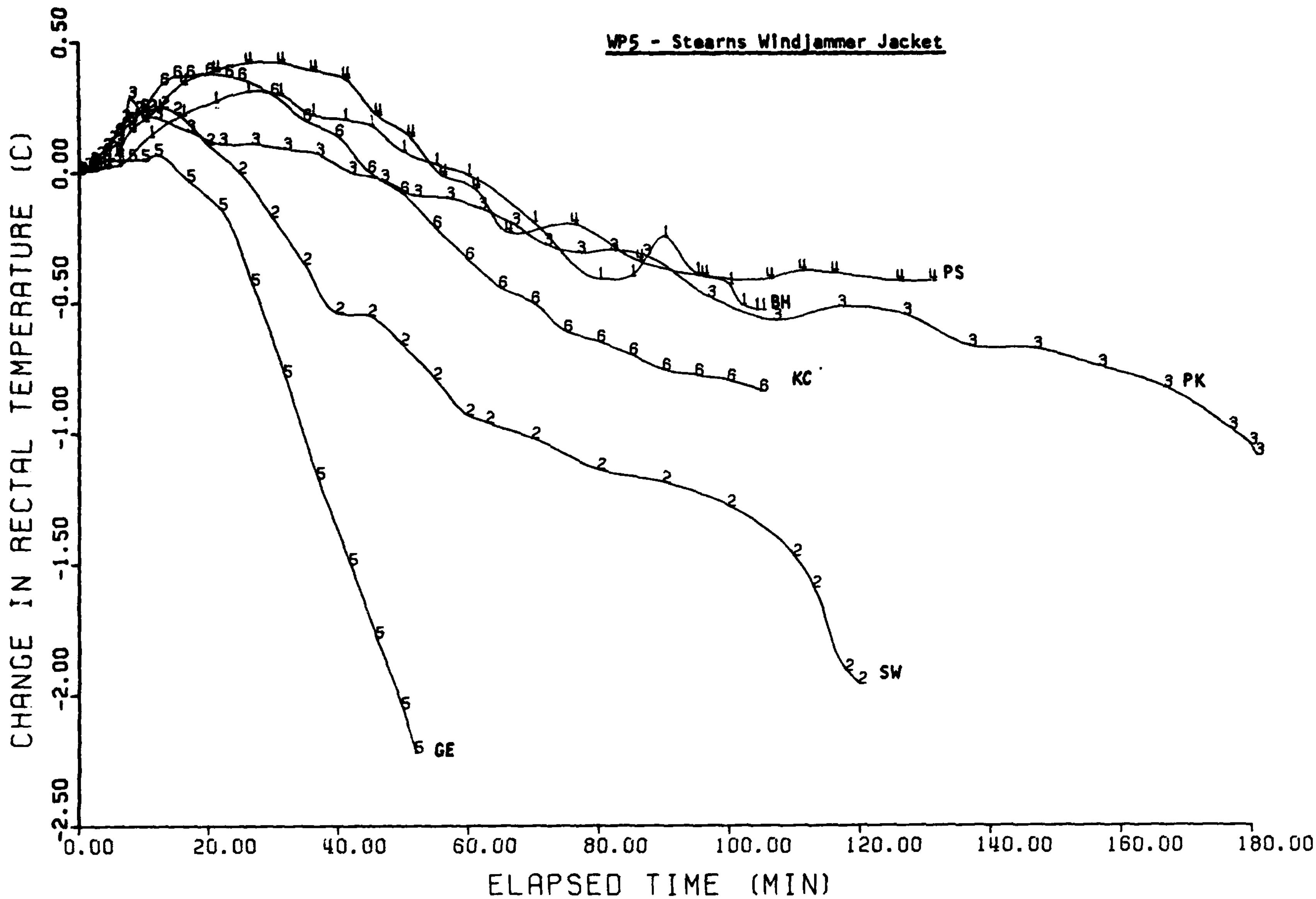
140.00
160.00
180.00
PK
BH
TP
MK
GE


WP5 - Stearns Windjammer Jacket
CHANGE IN RECTAL TEMPERATURE (C)
ELAPSED TIME (MIN)
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-2.00
-2.50
0.00
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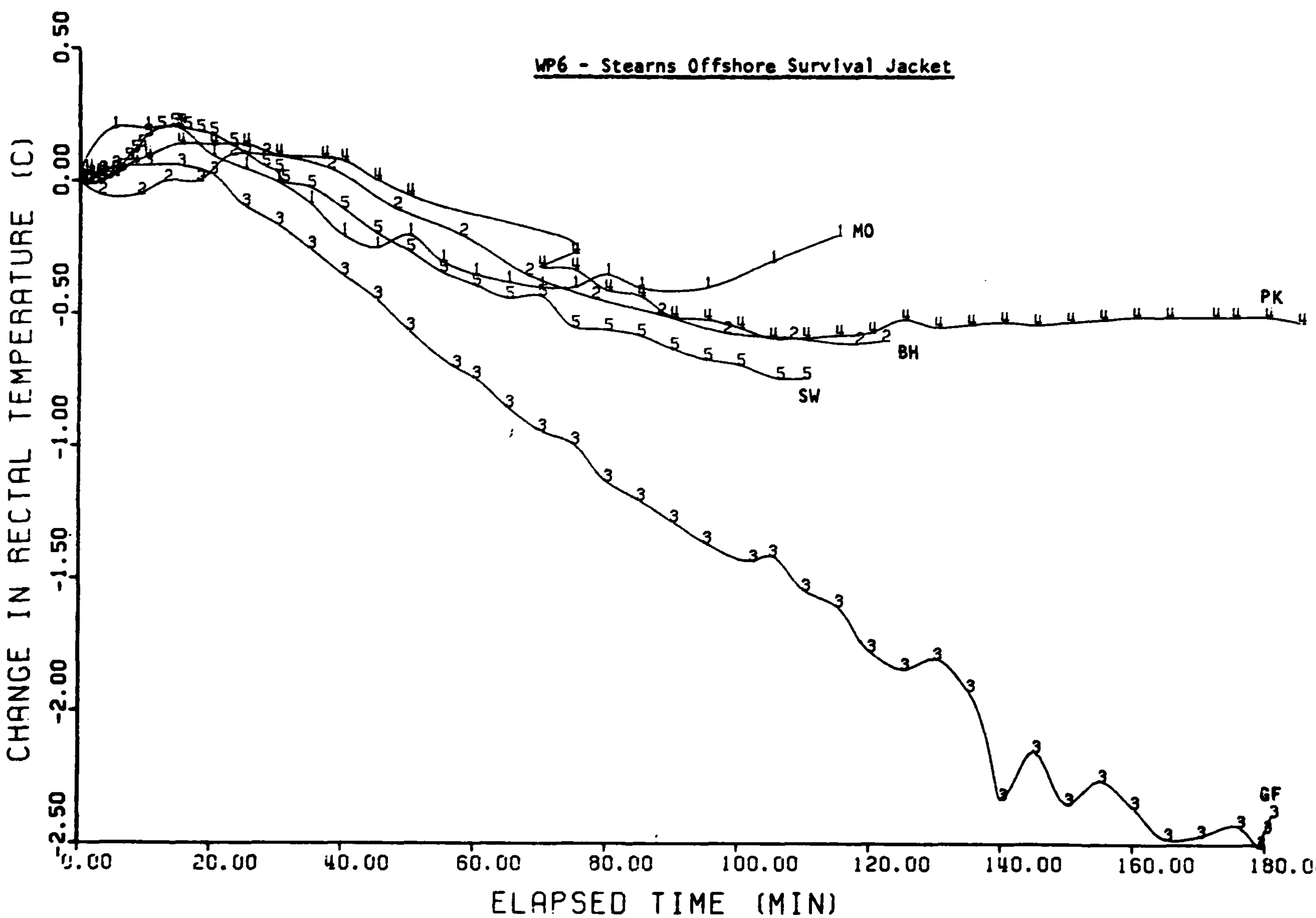
BH
KC
PK
SW
GE



WP6 - Stearns Offshore Survival Jacket
CHANGE IN RECTAL TEMPERATURE (C)
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-2.00
-2.50
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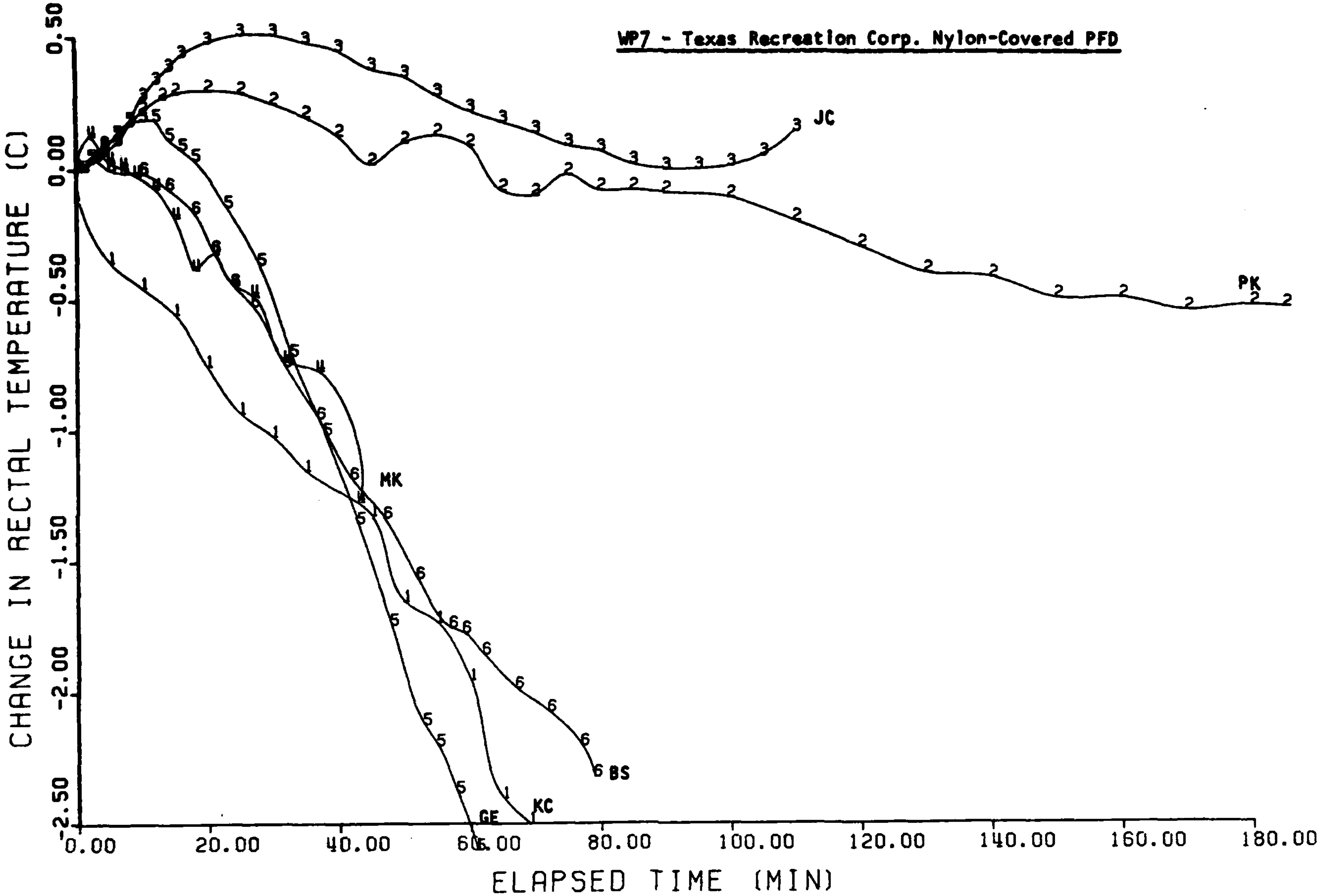
80.00
100.00
120.00
140.00
160.00
MO
PK
BH
SW
GF


WP7 - Texas Recreation Corp. Nylon-Covered PFD
CHANGE IN RECTAL TEMPERATURE (C)
ELAPSED TIME (MIN)
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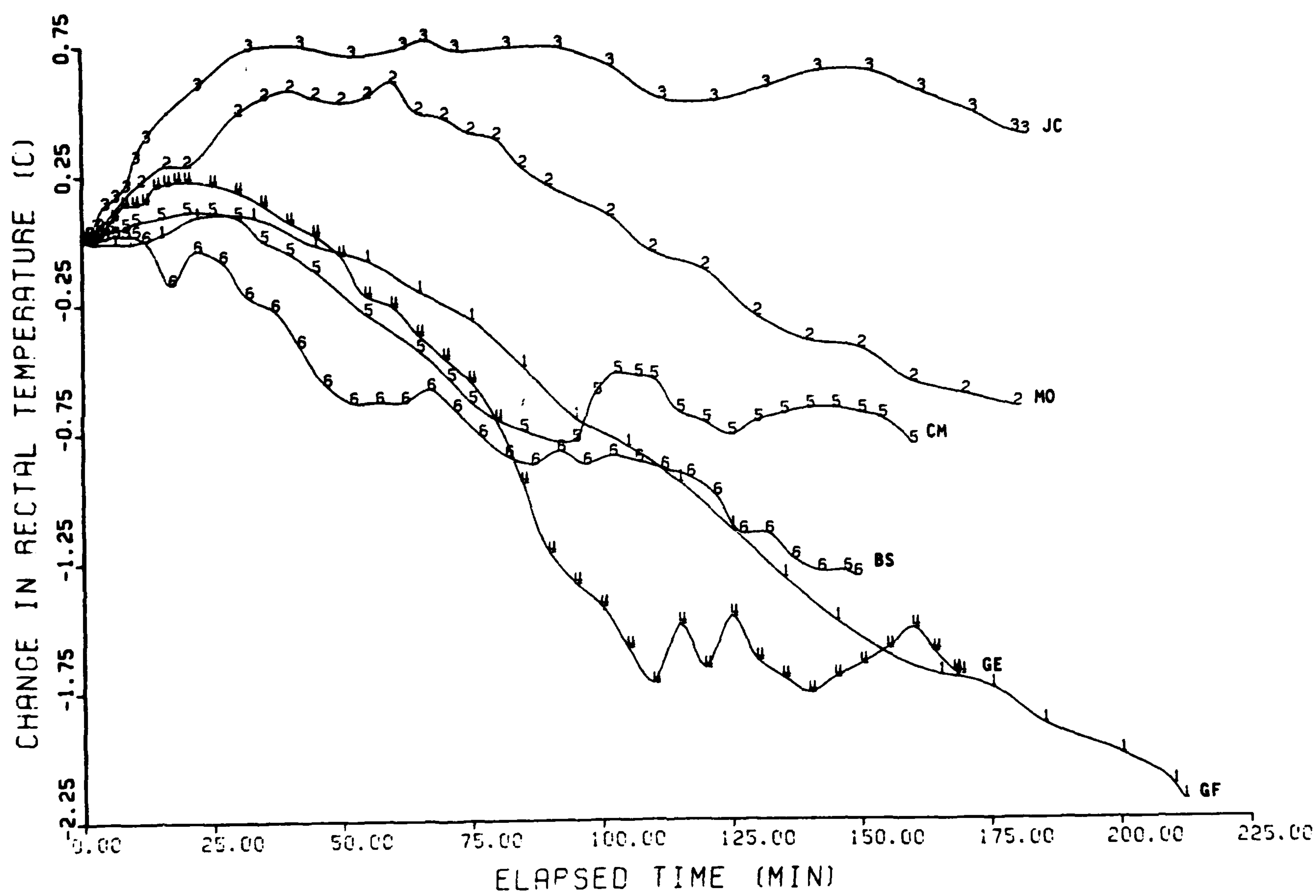
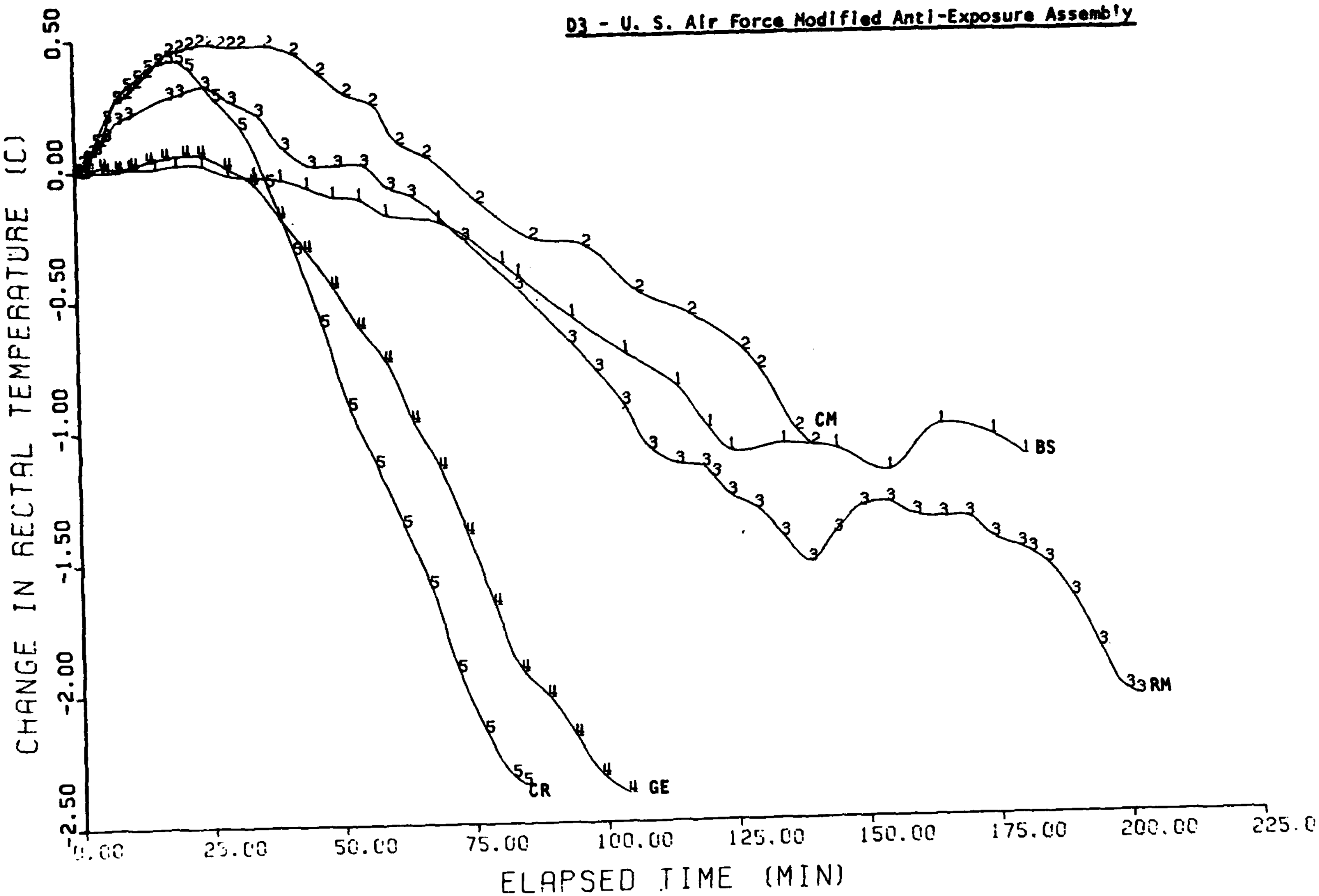
-1.50
-2.00
-2.50
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
JC
PK
MK
BS
KC
GE

D2 - NADC Goretex Experimental Coverall





D3 - U. S. Air Force Modified Anti-Exposure Assembly
CHANGE IN RECTAL TEMPERATURE (C)
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-1.50
-2.00
-2.50
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
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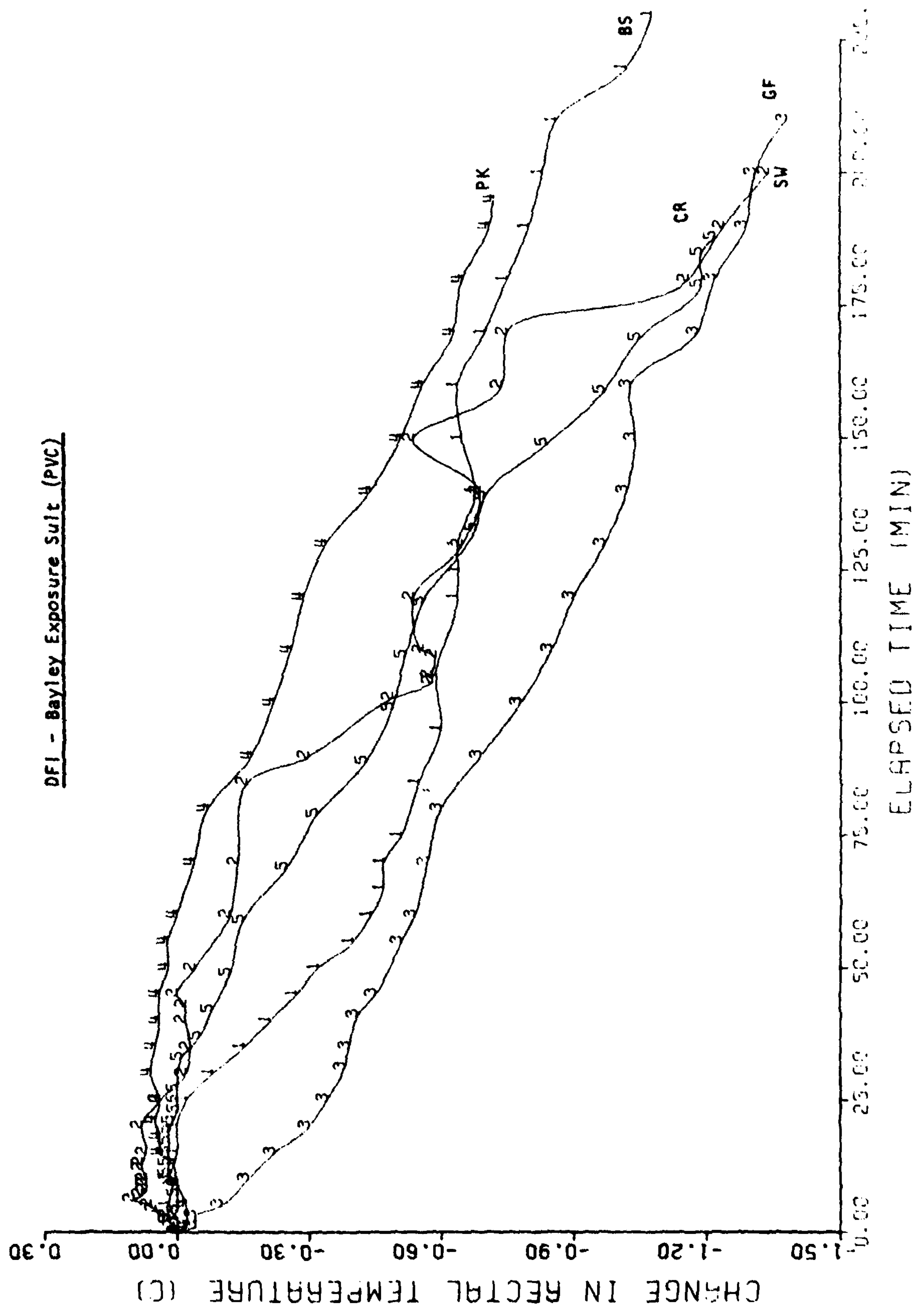
ELAPSED TIME (MIN)
CM
BS
RM
GE
CR


DFI - Bayley Exposure Suit (PVC)
CHANGE IN RECTAL TEMPERATURE (C)
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-0.90
-1.20
-1.50
ELAPSED TIME (MIN)
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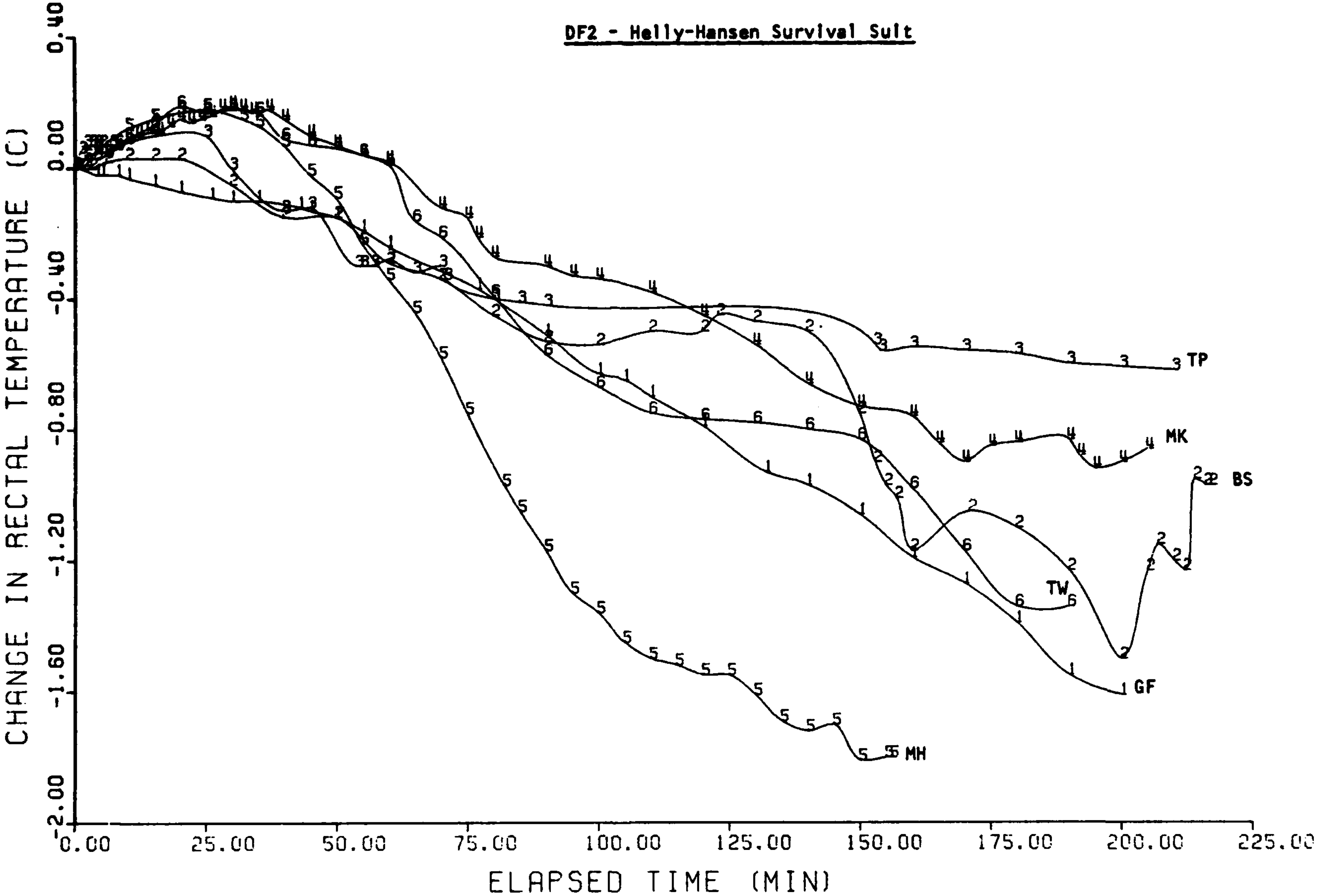
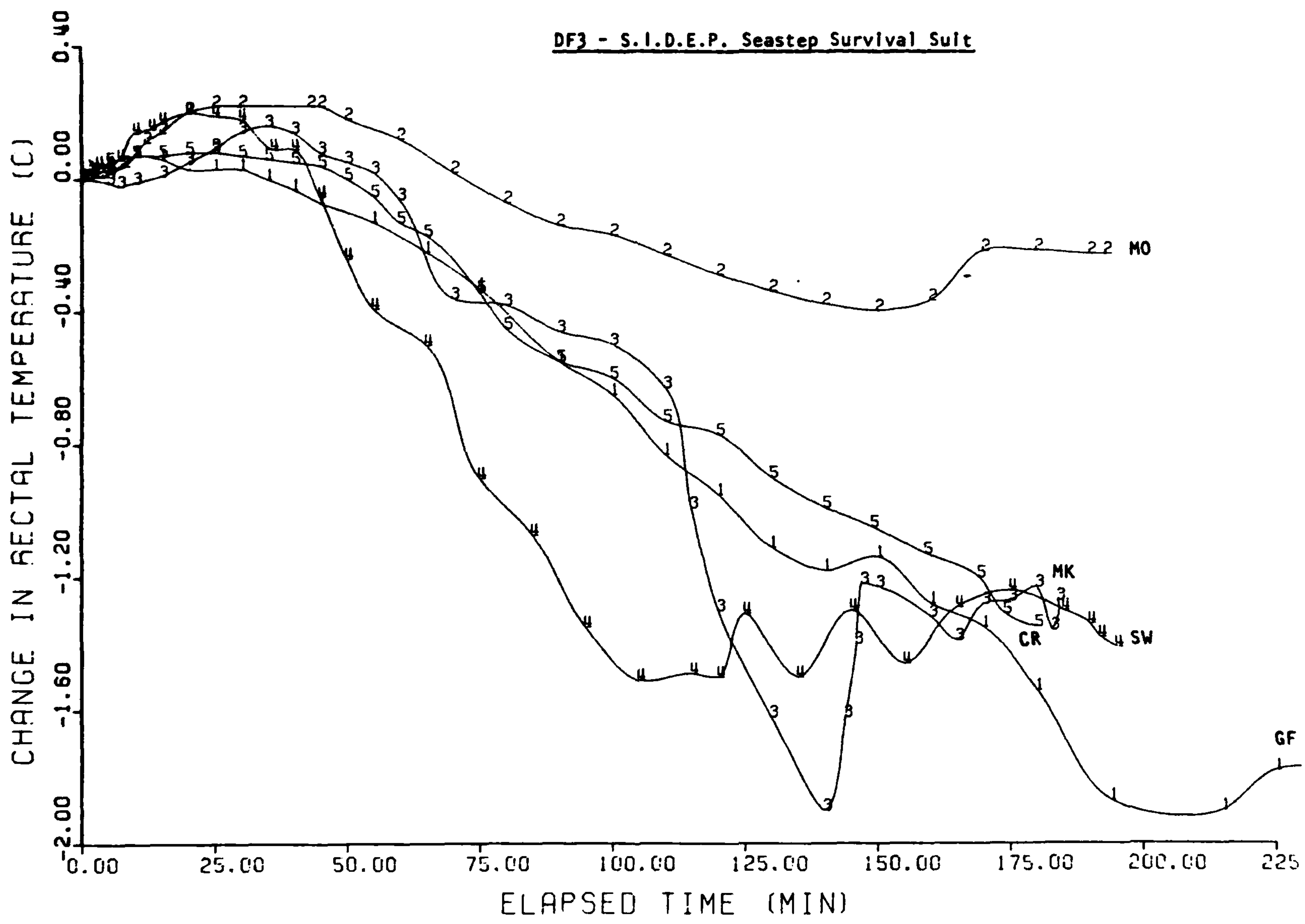
50.00
75.00
100.00
125.00
150.00
175.00
BS
GF
PK
CR
SW

DF2 - Helly-Hansen Survival Suit




DF3 - S.I.D.E.P. Seastep Survival Suit
CHANGE IN RECTAL TEMPERATURE (C)
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0.00
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-0.80
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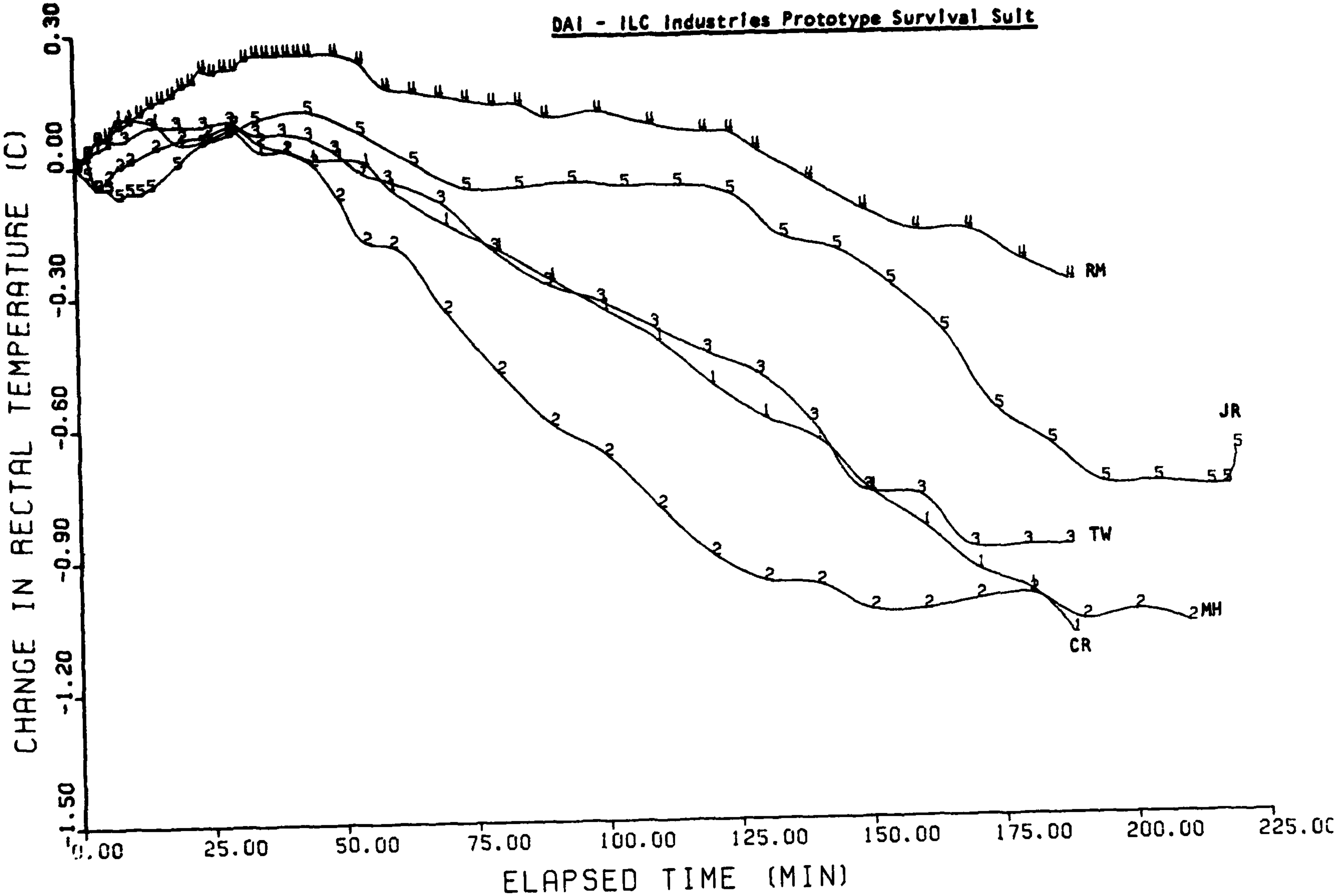
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
225
ELAPSED TIME (MIN)
MO
MK
CR
SW
GF



DAI - ILC Industries Prototype Survival Suit
CHANGE IN RECTAL TEMPERATURE (C)
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0.00
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-0.60
-0.90
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-1.50
ELAPSED TIME (MIN)
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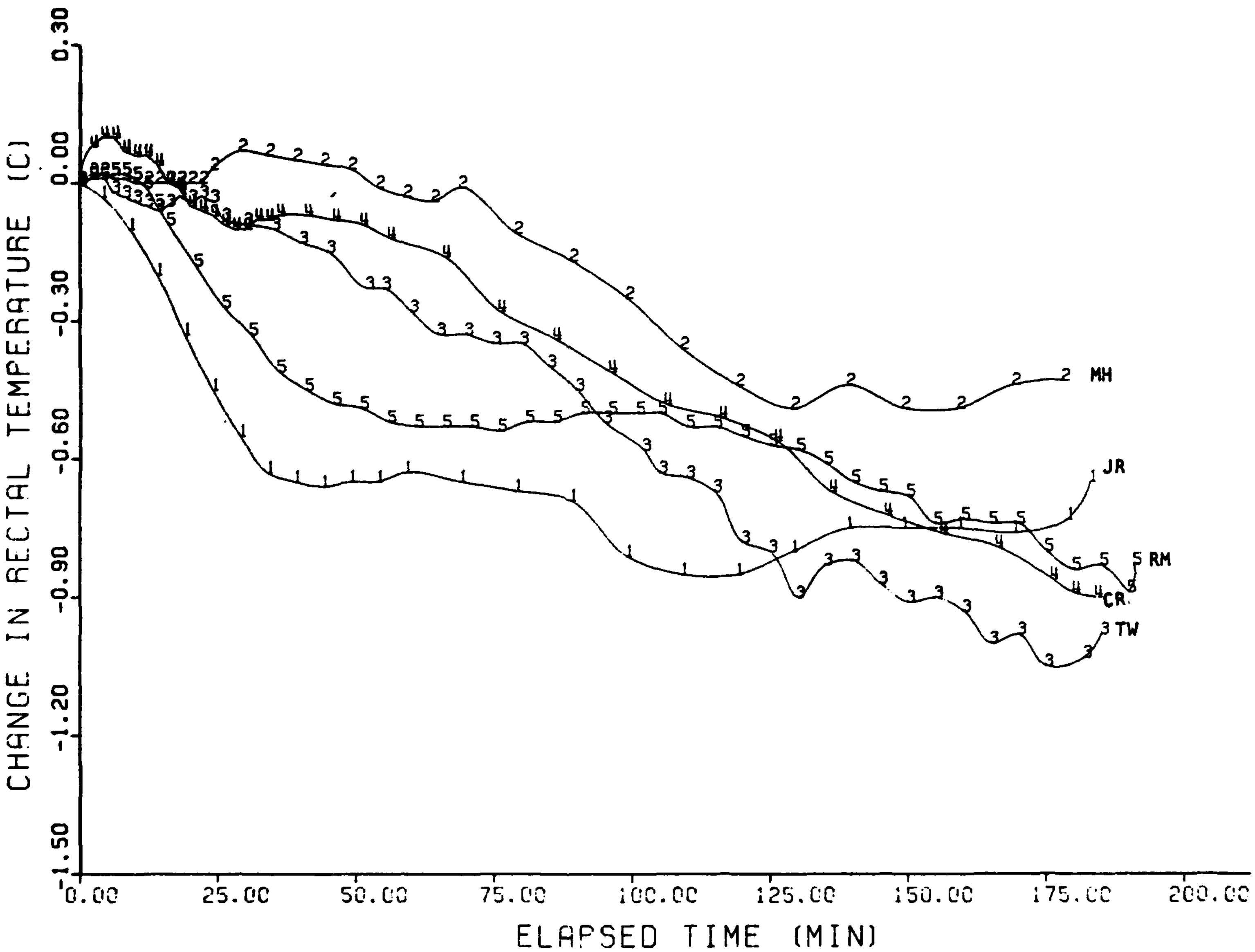
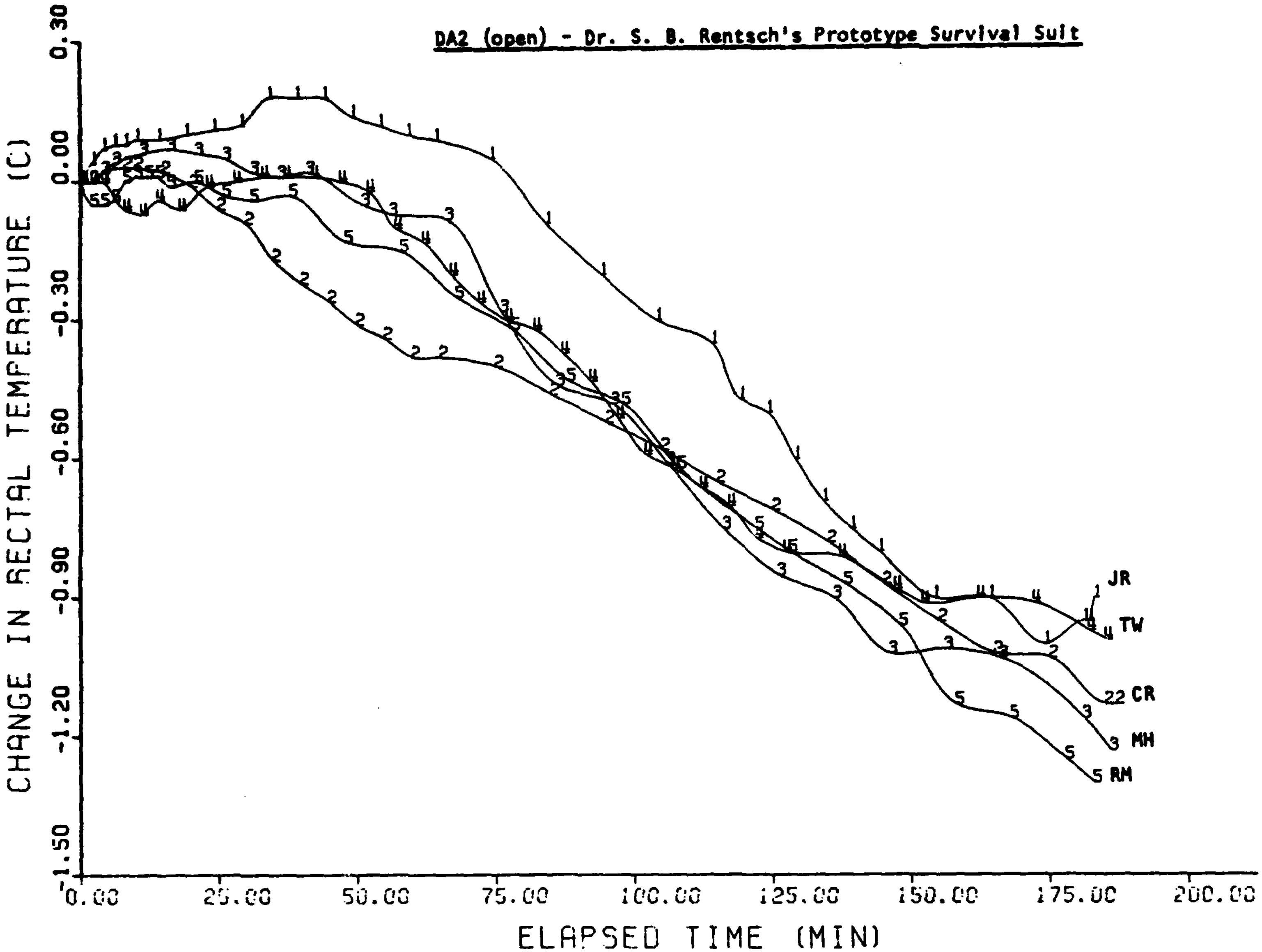
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
225.00
RM
JR
TW
MH
CR

DA2 (closed) - Dr. S. B. Rentsch's Prototype Survival Suit



DA2 (open) - Dr. S. B. Rentsch's Prototype Survival Suit



APPENDIX C

STANDARD PROCEDURES FOR MEASURING ELEMENTARY MOVEMENT RANGES OF MOTION

I. Shoulder

A. Flexion and Extension

1. Position

Subject is standing with arms at side.

2. Movement

Limb should travel forward with the palm of the hand facing the ceiling. Measurement is made from lateral aspect of the body. The subject's arm moves anteriorly in flexion and posteriorly in extension.

3. Method of Measurement

The goniometer is centered on the shoulder just below the acromion. The stationary arm of the goniometer is placed parallel to the mid-axillary line of the trunk; the rotating arm is placed parallel to the longitudinal axis of the humerus.

4. Normal Ranges of Motion

Flexion: 0° toward 170° to 180°

Extension: 0° toward 50° to 60°

5. Notes

Flexion:
- (a) Avoid extension of the trunk and abduction of the shoulder
- (b) Avoid elevation of the shoulder
- (c) Keep moving arm close to the body

Extension:
- (a) Keep subjects hand facing forward
- (b) Measurement may be made with elbow straight or flexed. We will use straight elbows.
- (c) Avoid forward flexion of the trunk
- (d) Avoid abduction of the shoulder

B. Abduction

1. Position

Subject is standing with his back to the operator. Arms are at subject's side.

2. Movement

Thumb leads in the direction of the movement, with the palm of the hand facing forward. Abduction is movement of the limb outward, away from the central plane of the body.

3. Method of Measurement

The goniometer is centered on the posterior aspect of the shoulder joint (on a level with a line projected posteriorly from below the acromion). The stationary arm of the goniometer is aligned parallel to the midline of the body (vertebral column). The rotating arm of the goniometer is aligned with the longitudinal axis of the humerus.

4. Normal Range of Motion

Abduction: 0° toward 170° to 180°

5. Notes

(a) Avoid lateral flexion of the trunk

(b) Avoid elevation of the shoulder girdle

(c) Avoid flexion or extension of the shoulder joint

C. External and Internal Rotation

1. Position

Subject is supine. Abduct the arm as near to 90° as possible with the elbow flexed to 90°. The full length of the humerus should be resting on the table top with only the elbow over the edge of the table. The forearm is perpendicular to the body with the palm facing the feet. If the subject is supine the humerus must be elevated with a pad to the plane of the acromion plane.

2. Movement

Keeping the humerus stationary, the forearm is rotated toward the feet for internal rotation and away from the feet for external rotation.

3. Method of Measurement

The goniometer is centered over the olecranon process. The stationary arm of the goniometer will be perpendicular to the floor (with the patient supine). The other goniometer arm is aligned with the longitudinal axis of the forearm.

4. Normal Ranges of Motion

External Rotation: 0° toward 90°

Internal Rotation: 0° toward 90°

5. Notes

(a) Avoid decrease or increase in abduction of the shoulder.

(b) Operator may steady subject's arm by placing a finger under the elbow to keep a reference point.

(c) Avoid flexion, extension or elevation of the shoulder.

II. Elbow

A. Flexion

1. Position

Subject is standing with the arm parallel to the lateral mid-line of the body and in the anatomical position. Palm of hand is facing forward.

2. Movement

Forearm remains in supination and rotates about elbow with palm facing ceiling. In flexion the hand moves toward the head.

3. Method of Measurement

The goniometer is placed over the elbow joint laterally. One arm of the goniometer is parallel to the longitudinal axis of the humerus and the other arm is parallel to the longitudinal axis of the radius. The axis will fall somewhere in the vicinity of the lateral condyle of the humerus. Set the instrument arms first and do not sacrifice their positions to secure the axis in a certain place.

4. Normal Range of Motion

Flexion: 0° toward 145° to 160°

III. Hip Joint

A. Flexion and Extension (knee straight)

1. Position

Subject is supine for flexion and prone for extension measurements.

2. Movement

In flexion (subject supine) the leg will pivot about the hip, away from the table. In extension (subject prone) the leg also moves away from the table.

3. Method of Measurement

The center of the goniometer will fall in the region of the greater trochanter. The stationary arm of the goniometer is placed parallel to a line from the greater trochanter of the femur to the crest of the ilium. This would parallel the long axis of the trunk. The

moving arm is placed along the lateral midline of the femur toward the lateral condyle. These placements are used for flexion and extension.

4. Normal Ranges of Motion
   Flexion: 0° toward 110° to 125°
   Extension: 0° toward 10°

5. Notes
   (a) In extension, avoid an arched back and an elevated hip
   (b) Knee will not be flexed.

B. Flexion (Knee bent)

1. Position
   Subject is supine with knee bent

2. Movement
   While keeping the knee bent at approximately the same angle, the entire leg is pivoted anteriorly about the hip.

3. Method of Measurement
   The center of the goniometer will fall in the region of the greater trochanter. The stationary arm of the goniometer is placed parallel to a line from the greater trochanter of the femur to the crest of the ilium. This would parallel the long axis of the trunk. The moving arm is placed along the lateral midline of the femur toward the lateral condyle. These placements are used for flexion and extension.

4. Normal Range of Motion
   Flexion: 0° toward 110°

C. Abduction and Adduction

1. Position
   Subject is supine in anatomical position.

2. Movement
   In abduction, leg moves away from body, rotating about hip. In adduction, the leg moves toward the uninvolved leg. The uninvolved leg will have to be moved to allow for adduction.

3. Method of Measurement

The stationary arm of the goniometer is placed on a line between the anterior superior iliac spines. The moving arm of the instrument is adjusted on the anterior surface of the thigh so that it parallels the dorsal midline of the femur toward the midline of the patella.

4. Normal Ranges of Motion

Abduction: 0° toward 45°

Adduction: 0° toward 15°

5. Notes

Adduction: (a) The pelvis will drop in movement, but this need not interfere with the placement of the instrument

(b) Avoid the body curling in the direction of motion

D. Internal and External Rotation

1. Position

Subject is sitting on table with knee flexed to 90° over the edge of the support provided. Sit erect and check the hip and leg line as follows: The anterior superior spine of the ilium, to the midline of the patella, the midline of the dorsum of the ankle, and the interspace between the second and third toes should be in the same sagittal plane. In the 0° position the tibia is perpendicular to the floor.

2. Movement

In the preferred position using the left leg, internal rotation is movement away from the uninvolved leg. External rotation is movement toward the uninvolved leg.

3. Method of Measurement

The goniometer should be centered over the mid-patella region and remain perpendicular to the floor, even though the leg will move from that position. From the 0° starting position, adjust the stationary arm parallel to the mid-line of the tibia. Place the moving arm of the goniometer along the crest of the tibia to a point midway between the malleoli (anteriorly). This procedure was followed for internal and external rotation.

4. Normal Ranges of Motion
   Medial Rotation: 0° toward 45°
   Lateral Rotation: 0° toward 45°

5. Notes
   (a) Avoid hip flexion, extension, abduction or adduction

IV. Knee Joint

A. Flexion

1. Position
   Subject is prone on table with toes extending over edge of table.

2. Movement
   The subject pivots the lower leg about the knee in a plane with the leg.

3. Method of Measurement
   The goniometer is centered over the knee joint laterally; the stationary arm is parallel to the longitudinal axis of the femur on the lateral surface of the thigh; the moving arm is parallel to the lateral midline of the fibula toward the lateral malleolus.

4. Normal Range of Motion
   Flexion: 0° toward 110° to 130°

V. Hand - Metacarpophalangeal Joints

A. Flexion

1. Position
   Subject places hand in any restful stable position with the thumb and fingers extended.

2. Movement
   Subject flexes each finger at joint in question.

3. Method of Measurement
   The goniometer is centered over the joint in question. The stationary arm of the goniometer is placed on the dorsum of the hand. The moving arm is placed parallel to the longitudinal axis of the finger being measured.

4. Normal Range of Motion
   Flexion: 0° toward 90°

VI. Spine

A. Flexion and Extension

1. Position
   Subject is standing in anatomical position with his side to operator.'

2. Movement
   In flexion, the upper torso is pivoted about the hips so the face is looking at the floor. In extension, the subject tilts his upper torso back so he is looking up. The legs should be kept perpendicular to the floor.

3. Method of Measurement
   The stationary arm of the goniometer is parallel to the floor on a line with the crest of the ilium. The moving arm is placed, at the end of the motion, along the mid-axillary line toward the tip of the shoulder.

4. Normal Range of Motion
   Flexion: 0° toward 80°
   Extension: 0° toward 20°

5. Notes
   (a) Avoid rotation and the tendency to flex the knees

*U.S. GOVERNMENT PRINTING OFFICE: 1980 634-120/668 1-3